Quick Scan Soils in The Netherlands

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Overview of the soil status with reference to the forthcoming EU Soil Strategy

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ABSTRACT

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In anticipation to the upcoming EU Soil Strategy, the ministries of LNV and VROM requested Alterra to provide a quick scan overview of the soil status in The Netherlands. The main aim of the study was to describe the current status of the soil of agricultural land with respect to the priorities (topics) selected by EU working groups. These working groups prepare background documents for the upcoming EU Soil Strategy. A second aim was to identify possible concerns with respect to soils in the Netherlands and possible conflicting views about these concerns. The topics selected include (i) soil organic matter, (ii) soil pollution (metals, nutrients, atmospheric N and S deposition and pesticides), (iii) soil erosion, (iv) soil compaction, (v) soil biodiversity, (vi) soil salinization and (vii) soil covering.
Soils in the Netherlands are in general man-made, fertile and wet. These characteristics are related to its geographic situation in a delta of major rivers draining a large area of agricultural and industrialized hinterland, and to the past and current land use. The land use in the Netherlands is highly intensive, and the agricultural production level per unit surface area is among the highest in the world. Most soils in the Netherlands have a fair to large amount of organic matter, because soils are fertile, and receive organic matter via crop residues and animal manure. The large import of animal feed for the large number of pigs, poultry and in part cattle in the Netherlands also contributes to the input of organic matter to soil. Yet, soils on average are loosing organic matter, as a consequence of drainage of peat soils, intensive soil cultivation, and uneven distribution of crop residues and animal manure. Especially peat soils are loosing organic matter through the oxidation of peat. Inputs of nutrients and heavy metals to agricultural land (2 million ha) exceed the output via harvested biomass, leaching and natural decomposition (attenuation). As a result, soils have become enriched, especially with phosphorus and heavy metals. It has been estimated that about 200,000 ha of land has heavy metals contents in soil that impair soil functions. An estimated 1,300,000 ha are phosphate saturated soils, where P leaching loss exceeds or will exceed ecologically tolerable limits. Governmental policies from the 1980s have been successful in decreasing the inputs of pesticides, atmospheric depositions of N and S, and of nutrients and heavy metals in animal manure and fertilizers into agricultural land. Further decreases are needed to be able to achieve the objectives of national and EU policy targets. Soils hold a huge biodiversity of soil life, but only few species are known yet. There is evidence that land use, soil cultivation and soil pollution has altered soil biodiversity. Such changes may have consequences for current and future soil functions. Soil compaction is often a result of the use of heavy machinery when the soil is wet. There is some evidence that soil compaction and especially sub soil compaction is increasing in scale and extent, but there is as yet little quantitative information. Soil erosion through overland flow and wind is locally of concern in the hilly löss area in the south and in the reclaimed peat lands in the *Veenkoloniën*, respectively. Soil salinization and soil covering (sealing) are also local phenomena. Both are increasing in scale. A continuing soil subsidence in combination with the steady sea level rise will contribute to increasing salinization of soils and surface waters and will force the Netherlands to take drastic structural measures in the current century.

Keywords: EU, soil, Netherlands, organic matter, pollution, erosion, biodiversity, salinization, cover

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Preface

The upcoming EU Soil Strategy may have consequences for policy on soils in EU member states. In anticipation to these possible consequences, the ministries of LNV and VROM requested Alterra to provide a quick scan overview of the soil status in The Netherlands. The first aim of the study was to describe the current status of the soil with respect to the priorities (topics) selected by EU working groups. These working groups prepare background documents for the upcoming EU Soil Strategy. A second objective was to identify topics, subjects, areas, concerns and views where opinions about the soil status differ among scientists or which are of particular interest to the Netherlands. The five topics selected are (i) soil organic matter, including peat degradation and subsidence, (ii) soil pollution (metals, nutrients, atmospheric N and S deposition and pesticides), (iii) soil erosion, (iv) soil compaction, and (v) soil biodiversity.

The study focuses on the rural area only. By far the greater part of the rural area in the Netherlands is agricultural land, intersected by small nature conservation areas, surface waters, and forests. Hence, this study focuses mainly on the soil status of agricultural land. As a consequence, industrial areas, waste dump sites, and urban areas are not included in this study.

There are close links between soil quality and water quality (groundwater en surface waters). This is especially the case for soils in lowlands like the Netherlands. The EU Water Framework Directive encompasses many Directives, including the Nitrates Directive and Groundwater Directive, which specifically addresses water quality. These Directives directly and indirectly also set targets for soil use and soil management, and thereby affect soil quality. However, this study does not address these linkages in policies and a possible urge for more integration.

Other aspects not addressed by this study for reasons of lower priority include:

- effects of land use changes; lowering of the soil surface due to oil and gas exploration, the quality of the sub soil (deeper soil layers beyond rooting depth);
- groundwater; coastal areas; dune migration; and aspects related to soil and cultural heritage.

A large number of scientists and policy makers from various Departments have contributed to this report. A first draft has been presented to members of the EU Working Groups in November 2003. A second draft has been reviewed by policy makers from the ministries of LNV and VROM in December 2003. A third draft has been commented by external experts and again by policy makers in February 2004. The final version includes all suggestions and comments made earlier, whenever plausible and possible (i.e. within the context of the study).

We would like to thank all contributors to this report for their suggestions and help!!
Paul Römkens & Oene Oenema

Excutive Summary

O. Oenema and P.F.A.M. Römkens

Background

There is growing awareness that intensification of agricultural production and soil use and management, industrialization, deforestation, and urbanization directly and indirectly affect soil quality and soil functioning. The intensification and changes in land use exert pressures on the soil through the loading of the soil with contaminants (heavy metals, pesticides), acidic atmospheric deposition, excess nutrients (nitrogen and phosphorus). The intensification and changes in land use may also contribute to physical soil degradation through erosion, depletion of soil organic matter, compaction, disturbance and sealing of soils. The consequence is a change of the functioning of soil in our society.

Main functions of soil in the society are:

- Bearing function, to carry our feet, buildings, cars and animals, and to let plants root into soil;
- Production function, to sustain sufficient and healthy plant and crop growth;
- Resource function, the soil as a source of resources for living organisms, industry, medicines, etc;
- Filter-, buffer- en reactor- function, to scavenge, transform and provide all kind of substance;
- Habitat function, soil as environment for organisms and nature; and
- Cultural and historical function; the soil as relict of the past, and soils to carry and form landscapes as art.

Though the threats and the vital role of soil in ecosystem functioning and society in the European Union (EU) are well-recognized, there is as yet no integral EU policy focused on soil protection and soil management in general. Various EU policy instruments do influence specific aspects of soil protection indirectly, but there is no integrated and systematic strategy for soil management and protection, and assessment of (changes in) its status on the basis of monitoring activities. However, there is growing awareness in the EU that the soil resource needs to be protected for sustainable development. The 6th EU Environment Action Program "Our Future, Our Choice" states that a thematic strategy for soil protection should be established. Currently, a number of EU thematic working groups and task groups are preparing arguments, suggestions and recommendations for setting up such a common EU soil strategy for soil protection, soil monitoring and a research agenda. Such an EU soil strategy should foster sustainable development and harmonize policies. On the other hand a common EU soil strategy should not frustrate current national policies and/or saddle individual member states with unrealistic targets.

The current report provides a quick overview of the status of the soil in the Netherlands. The report specifically addresses the topics and soil threats to be addressed in the forth-coming EU soil strategy, notably soil erosion, soil

contamination, soil sealing, soil compaction, soil organic matter, and soil biodiversity. It focuses on the rural areas, specifically on agricultural land. The soil status in urban and (former) industrial areas, landfills, oil spills, coastal areas are not addressed in this report.

Soils in the Netherlands

The Netherlands is situated in the delta of three major rivers. Especially the soils in western and northern half are heavily affected by the river loads and sediment quality inherited from the hinterland and the North Sea. Past land use and management also has had a tremendous effect on current soil quality and soil functioning. In general, soils in the Netherlands are wet, fertile, kept in a productive state and intensively managed. The northern and western half of the Netherlands is characterized by clay (8,000 km2) and peat soils (3,000 km2), with shallow groundwater levels. The central, southern and eastern half is characterized by sand (14,000 km2) and loss soils (900 km2), with shallow to relatively deep groundwater levels. Currently, about 60% of the surface area is agricultural land, 10% is natural area, 15% is urban and infrastructure area and 15% is surface water.

There are a number of human-induced threats for soil quality and soil functioning in the rural area (mainly agricultural land) of the Netherlands. Some of these have a regional to national impact whereas others only have a local-scale impact. Threats at regional to national scale include:

- Soil pollution through a diffuse but ongoing enrichment of the soil with heavy metals (especially Zn, Cu and Cd), pesticides, and nutrients (especially P and N);
- Soil compaction;
- Soil erosion;
- Threats with a local to regional scale impact are:
- Soil organic matter depletion;
- Soil salinization;
- Soil covering.

These treats of soil quality and soil functioning have different backgrounds and different complexities. They are briefly summarized below.

Soil organic matter

Organic matter has important functions in soil. It serves as substrate for soil life and it contributes to soil structure, nutrient and water retention, nutrient supply to plants, and to the retention and detoxification of contaminants. It buffers and mediates the release of greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) into the atmosphere. On a global scale, soils are a major store of carbon. The organic matter content in soils reflects the balance between inputs of organic matter (via litter, crop and root residues, animal manure and compost) and output (via decomposition of organic matter and transfer of litter and soil biomass). The time required for establishing equilibrium between input and output is long; therefore most soils are either accreting organic matter or are loosing organic matter, depending on the balance between inputs and outputs, and the time elapsed since large changes in land use and inputs.

Soils in the Netherlands are relatively rich in soil organic matter. This is related to (i) the wetness of many soils, which slows down the decomposition of organic matter in soils, (ii) the productivity of the soils in general, and (iii) the import and application of organic matter from abroad through animal feed. Grassland soils in general contain more organic matter than arable soils, because of continues cover and larger inputs via litter, root biomass and animal manure, and the lower decomposition rate (as there is no regular soil cultivation). Dune soils (Geestgronden), have low organic matter content, because of their relative youth and low productivity. Sandy soils usually have lower soil organic matter levels than clay soils, because of a lower productivity and higher organic matter decomposition rate (more organic matter in clay soils is physically protected from decomposition than in sand soils). Intensive soil cultivation, drainage and management accelerates the decomposition. All these factors together can explain why some soils contain less organic matter than others.

There are no systematic monitoring data available that allow to conclude that mean soil organic matter levels in soils in the Netherlands are decreasing or increasing. Certain trends suggest that the organic matter content has increased during the last decades, due to the increased productivity and increased import of organic matter (in animal feed) from abroad. Other trends however, suggest that the soil organic matter content has decreased, due to increased drainage, intensification of soil cultivation, more root crops and fewer cereals, and more frequent land use changes and less permanent grassland. Indeed, some soils have probably gained organic matter (notably permanent grasslands) while others have lost soil organic matter, notably peat soils and intensively cultivated soils. Simple input- output calculations suggests that the total stock of organic carbon in agricultural soils is decreasing, as estimated outputs via mineralization (6 Tg organic C per year) exceed total inputs of effective ('stable') organic carbon (3 Tg C per year). The difference would suggest that the soils in The Netherlands are loosing on average 3 Tg C per year. Most of this loss occurs in drained peat soils, that loose as much as 5 Mg C per ha per year or more, depending on drainage peat type and land use. This loss of SOC significantly contributes to the emission of greenhouse gases in the Netherlands in the order of 2-5% of the total national emission. This however is not reported in our National Inventory Report despite a binding international commitment. There is a considerable amount of uncertainty associated with these estimates, due to various general assumptions.

Some intensively managed soils are approaching or have reached already organic matter levels that are below the minimum level (from an agricultural point of view!) of about 1.5 to 2%. However, the question should be raised whether all combinations of soil type, land use and soil cultivation are suitable for the current intensive land use. Maintenance of soil organic matter contents in light textured soils, used for intensive cropping (root crops, bulbs, leafy vegetables, without cereals and cover crops in the crop rotation) at a level of 1.5 to 2% is not a realistic target. Soil organic matter levels below this target level increases the risk of yield depression due to increased leaching losses, drought, wind erosion, and surface crusting.

Summarizing, the combination of soil characteristics (light-textured soils), land use (arable cropping) and intensive soil cultivation will accelerate the depletion of soil organic matter to less than optimal values for arable crop production. Specific measures can reverse the depletion of soil organic matter by changing land use (other crops, including cover crops) and changing soil cultivation methods (minimum tillage). Part of such measures could be included in a package of cross compliance measures. There are as yet no specific standards and norms for soil organic matter and there is no national systematic monitoring program in the Netherlands.

Soil pollution

Main sources of diffuse soil pollutants at regional to national scales are atmospheric deposition, fertilizers, animal manure, and plant protection products (pesticides). These sources enrich the soil slowly but steadily either with unwanted substances or with wanted beneficial substances. Governmental policies have been successful in significantly decreasing the rate of enrichment. There are policies for sewage sludge, composts, pesticides, Cd in P fertilizers, and Cu, Zn, P and N in animal manure. However, various "relicts" inherited from the past are still present in the soil. Moreover, there is still a continued net enrichment of the soil for various substances, though at a (much) lower rate. The further enrichment of the soil with these substances will in turn affect soil biodiversity, diversity and quality of the crops and vegetation grown on the soil, and the quality of groundwater and surface waters (as a result of increased leaching) and atmosphere (greenhouse gases).

High levels of atmospheric deposition of S (SO_2) and N (NO_x and NH_y) species, especially in the second half of the 20th century have contributed to acidification and eutrophication of natural areas, including forests, heath land, lakes, fans, and streams. High inputs of S and N change the composition of the soil solution chemistry, lower the soil pH, and lead to increased leaching of basic cations. These changes in the soil and soil solution subsequently affect the natural vegetation, its sensitivity to drought and diseases, and its species diversity. High levels of atmospheric deposition of N and S species also decrease the abundance and composition of lichens. High inputs of atmospheric N ultimately lead to N saturation of natural systems and to increased leaching of nitrate to groundwater. Though the total atmospheric depositions of N and S have decreased greatly, starting with SO_2 and followed by NH_y (but NO_x not yet), total inputs of especially N into natural systems are still a factor of about two too high to achieve all objectives for biodiversity.

To obtain what is called an ecologically sustainable development, inputs of unwanted substances have to be decreased further. This is especially true for NH_y and NO_x in atmospheric depositions, various pesticides, Cd, N and P in inorganic fertilizers, and for Cu, Zn, N and P in animal manure. To reach a situation where no net accumulation occurs a huge economical effort is required . Such a situation is characterized by an equilibrium between outputs via harvested crop and natural attenuation (decomposition, leaching, and volatilization) and all inputs from fertilizers, atmospheric deposition etc.

Soil pollution inherited from the past locally and regionally pose problems. This is especially the case in the Kempen area where a large area has been contaminated with Cd and Zn from a nearby Zinc smelter, in floodplains of rivers (Rhine, Meuse, Scheldt, IJssel) and streams (Geul, Roer, Dommel), and in peat land areas, where the top soil has been amended with contaminated town waste, sludge and soil from elsewhere to strengthen the bearing capacity of these wet soils. All together, an area of about 200,000 ha has contents of heavy metals in the soil at which some soil functions are hampered. For example, the Cd content of certain crops (e.g. cereals) grown on these soils exceed current food quality standards imposed by national or EU regulations.

Recently, the area of so-called phosphate saturated soils has been estimated at 70-80% of the total area of agricultural land, i.e. about 1400,000 ha. This estimate is sensitive to the assumptions used in the calculations, and uncertain therefore. There is agreement about the protocol to be used for the calculation of phosphate saturated sandy soils but not for that of clay and peat soils. Whatever the exact definition and assumptions, the area of phosphate saturated soils is large.

The ecological impact of soils with too high contents of metals and/or P differs from site to site. These areas require risk based land management, which still has to be developed and implemented. Soils with high metal contents used for arable land are a risk for food safety. Soils with high contents of metals and/or P obstruct nature development and obstruct also the progress of the reconstruction of rural areas towards more sustainable development.

A recent development in relation to Water Framework Directive and the upcoming EU soil strategy is the linkage of water quality and soil use and management. Objectives for water quality will be translated into targets for soil use and management. Depending on the (regionally defined) objectives for water quality, this linkage may require drastic decreases in the input of P, N and metals like Cu and Zn in animal manure in some regions. Evidently, care need to be taken that objectives for water quality do not lead to unrealistic targets for soil use and management in the Netherlands.

Soil erosion

Soil erosion is defined as the physical removal (transportation) of soil particles by water or wind to elsewhere. Soil erosion by water and wind occurs naturally and continuously at low rates, depending on soil characteristics, soil morphology, soil exposure, climate, and vegetation cover. Because of this manifold of influencing factors, spatial and temporal variability in soil erosion is very large.

Soil erosion has impact on areas that lose soil material and on areas that receive soil. Generally, areas that lose soil suffer from decreased productivity. Areas receiving sediment are generally known for their fertility and productivity. The Netherlands have been a net sediment accreting delta for millennia, though periodic storm floods have eroded large areas again. The building of dikes has protected the Netherlands

both from sediment accretion and from erosion by storm floods. This has changed the Netherlands from a sediment accruing delta to a sinking basin.

At present soil erosion in the Netherlands is only locally and regionally a problem. The combination of soil characteristics and current land use practices make the sandy soils in the Veenkoloniën susceptible to wind erosion during dry periods in winter and spring. Serious wind erosion in this area occurs once every 5-15 years. Average annual damage has been estimated at about 9 million Euro. Specific measures are being taken to decrease the occurrence of wind erosion, e.g. by growing cover crops, applying surface coatings (animal slurry), change of soil cultivation, and changes to permanent crops. Part of such measures could be included in a package of cross compliance measures. There are a number of aspects related to wind erosion:

(i) loss of fertile top soil at one site and sedimentation of fertile soils elsewhere
(ii) blistering of crops, erosion of seedlings, and crop yield reduction
(iii) aerosol formation and decreased visibility (dustbowl);
(iv) filling of ditches, damage of water works and roads; and
(v) pollution and eutrophication at receiving sites.

The combination of soil characteristics (loss), undulating terrain and local land use (arable cropping) makes areas in the province Limburg susceptible to erosion by water. Long-term monitoring studies indicate that the annual soil loss is 14 ton per ha in some municipalities. In total about 300 locations are subject to damage due to water erosion. Specific measures have been taken to decrease the risk of erosion, e.g. by growing cover crops, proper soil cultivation techniques, terracing, and by growing permanent crops. Part of such measures could be extended further in a package of cross compliance measures.

Soil compaction

Soil compaction is defined as 'densification and distortion of soil structure'. Compaction leads to a decrease of total and air-filled porosity and permeability of soils. Compaction lowers the productivity and biological activity of the soil, and increases the risk for waterlogging, flooding, soil erosion and nutrient losses via run off and denitrification. 'Over-compaction' is defined as the visual degradation of soil structure and soil physical properties, which result in major reductions of crop yield and water infiltration rate.

There is not much quantitative information about compaction of soils in the Netherlands. Most farmers are well-aware of the risks of soil compaction, and try to avoid compaction but are not always in the position to plan and execute field activities without compaction. Moreover, soil compaction is not always easily visible, except in case of incised wheel tracks, ponding of water and local plant growth distortions. There are no accurate data about mean yield loss through compaction in The Netherlands, but field experiments indicate that the local loss of crop yield can be as high as 15 to 38% under unfavorable field conditions.

Soil compaction is mainly the result of the use of heavy machinery. Tractors and machines for animal slurry application and harvesting of grass and maize silage, sugar

beet, potatoes and cereals have greatly increased in size and weight during the last decades. Initially, solutions were sought in increased number and size of wheels and in decreased tire inflation pressure. In practice however, wheel loads of the machines are often high, and this requires high tire inflation pressures, even if large tires are used. Another trend is that application of animal slurry and harvesting of grass and maize for silage, and sugar beet, potatoes, and cereals are often being done by contractors. This makes timing of the field activities during days when soils are dry and capable not always possible.

A special case is subsoil compaction with panlayer formation. The panlayer is caused by the tractor tires driving on the subsoil during ploughing and by very high wheel loads. This panlayer is less permeable for roots, water and oxygen than the soil below it and thereby is key to the functioning of the subsoil. Due to increasing high wheel loads compaction spreads ever deeper into the subsoil. Contrary to the topsoil the subsoil is not loosened by soil cultivation annually. Therefore, the resilience of the subsoil for compaction is low.

There is no monitoring of soil compaction in practice in the Netherlands. Furthermore, there has also been no field research on soil compaction during the last 15 years. The reason for ignoring soil compaction is (i) the fact that soil compaction is not easily recognized in the field, (ii) the believe that it can be solved technically, and (iii) the experience that yield reduction by soil compaction can be relieved in part by application of more fertilizers (which are cheap). Experimental evidence from abroad does suggest that this view might be too simple. These experiments suggest that soil compaction is a creeping process, which is affecting large areas of agricultural land. Exploring the extent and seriousness of soil compaction in practice is recommended.

Soil biodiversity

Soils contain a huge diversity of all sorts of macrofauna and especially microfauna and -flora, but actual numbers have not been quantified, and are hard to quantify yet. Despite the limited insight in the diversity of fauna in soils, there is evidence that biodiversity has been altered by the (intensive) use of the soil. Inventories suggest that changes in species composition occur, rather than in absolute number of species. It should be noted that no reference conditions and values are available for benchmarking. Under extreme conditions such as serious acidification, pollution, intensive soil use in agriculture, species diversity will also decrease. There are also indications that the functional stability of soils is lower in polluted and intensively used soils than in unpolluted, extensively managed soils.

Prevention of further deterioration and restoration of biodiversity in agricultural areas may contribute to the accomplishment of national biodiversity policy goals. Impoverishment of soil biodiversity may pose risks to organic matter quality and structure of soils. This will matter most in areas where agricultural land is converted to natural areas, as these soils often lack structure and contain reduced levels of organic matter.

In the transition towards sustainable agriculture, it is necessary to increase the biological suppression of soil borne diseases in order to reduce the use of (chemical) pesticides. In this process the (microbial) biodiversity plays an important role. When less pesticides and chemical fertilizers are used, and less manure with less nitrogen and phosphate are applied, soil life will play a bigger role in nutrient cycling and suppression of diseases. In that case nutrients will become available to crops mainly by mineralization processes, symbiosis between plants and fungi (mycorrhiza), and nitrogen fixing micro organisms. Thus, a transition towards sustainable agriculture has to be accompanied by a change of soil life. An important question is how and how quickly soil communities change as a consequence of changing agricultural practices (e.g. reduced fertilization, wider rotations) and what this means for nutrient cycling and soil health. There is some evidence that for both sustainable agriculture and nature restoration, an increase of fungi and fungi-eating organisms in soil are required.

With current methods only the diversity of the most abundant species is measured. To improve the monitoring of more rare species molecular techniques are needed. Because of the enormous diversity of soil species, for practical reasons the bulk of scientific research in this field is focused on functional biodiversity. This includes (groups of) organisms that make a relatively large contribution to the properties of the soil that matter most to land use or to the functioning of the ecosystem as a whole, i.e., to ecosystem health and life support functions (also called ecosystem services). There is still insufficient scientific understanding of the requirements of soil biodiversity to support the mentioned functions or services, both qualitatively and quantitatively. Because biodiversity is a very complex issue by nature and because reference conditions are not or poorly documented, it is hard to establish definitive criteria for it. Monitoring, maintaining and fostering biodiversity is already difficult enough for the time being. The basic goal for soil biodiversity is that there should be no local reduction.

The largest database with respect to functional biodiversity in rural areas has been composed within the framework of the development of a Biological Soil Indicator. This was done for the Dutch national soil monitoring network in commission of the ministries of VROM and LNV by RIVM, Alterra and the department of Soil Quality of Wageningen University.

Soil salinization

Soil salinization is defined as the increase in the contents of soluble salts (mainly sodium, chloride, sulfate, and carbonates) in soil, groundwater and surface waters. Soil salinization deteriorates soil structure and decreases productivity through salt-induced stresses (drought, malnutrition, and chlorosis). It affects crops that are sensitive to salt stress (vegetables, potatoes) and fresh water fauna and natural vegetation.

Soil salinization is not (yet) a big problem in the Netherlands, because of the large precipitation surplus, which washes excess salts from fertilizers, manures, compost, and atmospheric deposition ultimately to the sea. Soils are also permeable, which

facilitates leaching. However, half of the Netherlands is situated below sea level, and this makes this area sensitive to salinization through seepage of sea water. Soil salinization occurs especially in dry summers in the low-lying areas in the north-western half of the Netherlands. Problems occur in some polders in the Provinces of Zeeland (Schouwen Duivenland), Zuid- en Noord-Holland, Friesland and Groningen, through seepage of salt or brackish groundwater. Seepage is increased in dry summers when groundwater level drops, which is in part accelerated through groundwater extraction for purposes of irrigation, drinking water supply and industrial activities. Seepage is also increased through subsidence; the surface level of the Netherlands subsides relative to the mean sea level (rise). This relative subsidence is a slow but ongoing process; it steadily increases soil salinization.

Local problems of soil salinization can be relieved through water management, and soil and crop management. Water management is very important, as some crops are particularly sensitive to irrigation of salty water (with high chloride content). Water authorities (waterschappen) and various farmers monitor the concentrations of salts (chloride) in canals and ditches, to allow prediction of salt damage upon irrigation. Crops sensitive to salts can not be grown in such condition.

Soil covering

Soil covering is defined as sealing of the soil surface, which effectively reduces the exchange of water, matter and life between soil and atmosphere to zero and results in a virtually dead (or at least severely disfunctional) soil. Water and matter that are deposited on covered soils move sooner or later to central collectors or to the borders of the covers. Hence, any deposited matter is concentrated on a smaller area; the covered soil is not participating in exchange and natural attenuation processes. Evidently, when all soils are covered, the terrestrial biosphere has gone. But what is the maximal acceptable (tolerable) coverage in the world, in the Netherlands? This question has not been answered yet.

Soil covering occurs in urbanized and industrial areas, roads and glasshouse horticulture and floriculture. Approximately 15 % of the surface area in the Netherlands is urban, industrial or infrastructural (roads), which is equivalent to approximately 5000 km^2. A significant fraction (10 to 50%) of this area is soil-covered (500 to 2500 km^2). Glass houses cover approx. 250 km^2 (25.000 ha).

Summarizing, a relatively large area of soil in the Netherlands is partly or completely covered (sealed). Coverage changes the flow of water and matter, but there are not signals from practice that possible problems related to these changes can not be solved technically so far. There are no standards or norms for acceptable covered areas. Increasing coverage will ultimately contribute to the collapse of the terrestrial biosphere.

Conclusions

This study presents a quck scan overview of the soil status in rural areas in the Netherlands, with reference to relevant topics of the forthcoming EU soil strategy. The conclusions pertinent to agricultural land are as follows:

- In general, soils in the Netherlands are man-made, fertile (productive) and wet (for at least part of the year);
- Approximately 200,000 ha of agricultural land and nature conservation land contain heavy metals at such high level that some soils functions are distorted;
- An estimated 1,400,000 ha of agricultural land has phosphate-saturated soils, but there is considerable uncertainty in the actual area and the actual ecological impacts of these soils now and in the near future. The assumptions and protocol for the assignation of all soils have not been approved yet;
- Governmental policies have been successful in decreasing the accumulation of heavy metals and phosphate in soils during the last decades, but the accumulation still continues (though at a decreased rate) suggesting that the affected area will continue to increase further;
- There is some evidence that the incidence of (sub-surface) soil compaction has increased during the last decade due to the increased use of heavy machinery by contractors during moments when the soil is susceptible to compaction, but the size of the affected area and the seriousness of compaction are as yet unknown;
- There is evidence that some soils (especially drained peat soils) are loosing organic matter, due to increased drainage, intensive soil cultivation, and changing crop rotations (less cereals and more root and tuber crops). However, a systematic monitoring of soil organic matter contents and documented reference conditions are not available. Some soils contain only 1.5 to 2% organic matter or less, which is considered to be a minimum level for good agronomic use. It is questionable whether all current combinations of soil type (e.g., light-textured soils) and land use (e.g., intensive cultivation of root crops and leafy vegetables, without cover crops or cereal crops) are sustainable in the near future. Formulation and implementation of good agricultural practices within the framework of cross compliance could help to reverse the trend of decreasing organic matter in some of these soils;
- There is also evidence to suggests that some soils (for example permanent grasslands) have gained and are gaining organic matter, because of the increased productivity of the soil and the increased amounts of animal manure applied (derived for a large part from imported animal feed). Current grassland management includes grassland renovation and changing land use to (temporary) cropland and this likely does revert the gain in organic matter. The area of permanent grassland has decrease over the last 5 decades;
- Salinization of soils, groundwater and surface waters occurs locally in low-lying polders and along the coast. It is suggested that the area and seriousness of salinization is increasing, mainly because of the subsidence of the land and the sea level rise;
- In urban and industrialized areas, roads and areas with glasshouses, a large fraction of the soil is covered (sealed), thereby restricting soil life and the exchange of matter between soil and atmosphere. The acceptable area of soil coverage is not known and has not been discussed as an issue in The Netherlands, yet;
- Soils contain a huge biodiversity, but most of the species and possible specific functions remain yet unknown. There is evidence that species composition of the soil life has changed in response to introduction and intensification of agricultural

practices. There is also evidence that serious soil pollution and acidification has decreased species diversity, but the amount of field data is too limited to draw firm conclusions;

- There is evidence to suggest that (functional) biodiversity is important for soil born disease suppression and nitrogen mineralization, and thereby for the transition towards ecologically sustainable agriculture.
- Currently, there are no systematic monitoring programs for soil organic matter, soil compaction, soil phosphorus and soil erosion in agricultural land. There are also no clear standards or yardsticks, which allow to evaluate whether soil organic matter level or soil compaction is too high or too low. Further, soils are very variable in space, which complicates accurate assessment of the mean composition and characteristics of the soils. This also complicates the establishment of accurate trends in changes of soil composition and characteristics.
- There are differences in opinions and concerns about the seriousness of phosphate-saturated soils, decreases in soil organic matter, soil subsidence due to peat land degradation, soil compaction, wind erosion, water erosion, and salinization. These differences are related to differences in perception between individuals, but are not further addressed. With reference to the forthcoming EU soil strategy, concerns seem to be most serious for the increasing areas of phosphate saturated soils and heavy-metal polluted soils, and for peat land degradation, which results in subsidence and increased salinization and in significant emissions of greenhouse gases CO_2 and N_2O. Concerns related to soil organic matter losses, soil compaction and soil biodiversity shifts do however require attention and a change in soil management.
- Finally, there is a fair amount of speculation in some of the formulated conclusions. This reiterates the need for quantitative field data to be able to confirm or adjust the conclusions above. Based on this study we may conclude that implementation of the EU soil strategy will require carefully designed monitoring programs, using harmonized EU protocols where possible and available.

1 Introduction

O. Oenema

1.1 Soil in a global perspective

Terrestrial soils cover 29% of the total surface area of the earth. Together with the oceans, terrestrial soils are the link between the earth and the atmosphere. Soils support life on earth and regulate with the biosphere and oceans climate on earth. The old Chinese and Greek cultures knew already that soil is a cornerstone of the universe, but the role of the soil was not well-understood at that time. Science has largely ignored the soil, until the early 19th century. From that time onwards, the characteristics and functions of the soil below the surface were studied systematically. This knowledge has greatly contributed to the development of modern agriculture from the end of the 19th century onwards (e.g. Smil, 2000). However, the global picture, the role of soil in the functioning of the global biosphere was not studied until recently, and we still don't know much about it (e.g. Smil, 2002). Of course, soils are of prime importance in global food production, but the role of soil in sustaining the global biosphere and climate on earth is not understood in a quantitative way yet. This notice is important, as modern civilizations have altered soil quality at increasing scale, through industry and agriculture, especially during recent decades.

By 2050, global population is projected to be 50% larger than at present and global grain demand is projected to double. This doubling will result from a projected 2.4 fold increase in per capita real income and from dietary shifts towards a higher proportion of meat. Further increases in agricultural output are essential for global political and social sustainability and equity. Doing so in ways that do not compromise environmental integrity and public health is a great challenge. The demands from the soil will increase. Currently, 3% of the global surface area is arable land, 7% is grazing land, 8% is forest and 12% is bare soil (deserts and land covered by rock, snow and ice). The surface areas of arable land and grazing land cannot simply be extended at the expense of for example forests. The current area of arable land and grazing land is also more or less the area that can be used for future food production. Hence, satisfying the increasing global food demand has to come from increasing yields per unit of surface area and from changes in dietary patterns.

Fertile soils with good physical properties to support root growth are essential for sustainable agriculture. Since 1950 approximately 5% of the global surface area of agricultural land has undergone human-induced soil degradation and loss of productivity, often from poor fertilizer and water management, soil erosion and shortened fallow periods. Continuous cropping and inadequate replacement of nutrients removed in harvested materials or lost to the wider environment have depleted soil fertility on large areas, especially in Sub-Saharan Africa. The effects of soil degradation on productivity can sometimes be compensated for by increased fertilization, irrigation and disease control, but with increased production costs.

Proper crop rotations, cover crops and fallow periods, manuring and balanced fertilization can help maintain and restore soil fertility (e.g. Tilman, et al., 2002).

The role of soil on earth is complex, because soils have many functions and because soils are diverse, both in space and with depth. Commonly, the following six functions are assigned to soils:

- Bearing function, to carry our feet, buildings and cars, and to let plants root into soil;
- Production function, to sustain plant growth;
- Resource function, the soil as source of resource for living organisms, industry, medicines, etc;
- Filter-, buffer- en reactor- function, to scavenge, transform and provide all kind of substance;
- Habitat function, soil as environment for organisms and nature; and
- Cultural and historical function; the soil as relict of the past and soil as art.

Soils may differ greatly in carrying out these functions. Even similar soils but at different sites may differ in their capacity to function, because of the role of the wider environment. Currently, we know more about the first three to four soil functions than about the last mentioned two to three functions. However, we realize more and more that the last three are also extremely important for (human) life on earth and ecosystem services. Basically, the filter-, buffer and reactor functions of the soil make the link between earth and atmosphere.

1.2 Soils in the European Union

The current 15 member states of the European Union (EU-15) cover 2.15% of the global terrestrial area. On average 40% of this area is used for agriculture, but this percentage ranges between 7% for Finland and Sweden to 60% for the Netherlands, 63% for Denmark and 66% for the United Kingdom.

Soils in the European Union are diverse, ranging from very shallow rocky soils at northern latitude in Scandinavian countries and at high altitude in central Europe, to deeply weathered, depleted red soils in the Mediterranean, to fertile alluvial clay soils in deltas and peat soils in depressions. Large areas are covered by light-textured sandy soils especially in north and central Europe.

Agriculture and urban and industrial areas utilize the better and fertile soils, while forests and natural vegetation is mainly found on shallow, sandy, poor, wet soils. On average 37% of the agricultural utilized area is used for permanent grassland, but this percentage ranges from 5% for Finland to 14% for Denmark, to 53% for the Netherlands to 64% for United Kingdom and 69% for Ireland.

The diverse soil conditions and land use in member states are depicted also on soil maps which show the geographic distribution of soil types, soil texture, soil organic matter, soil wetness, stoniness, land capability, etc. Such maps have been established some 50 year ago in response to the need to ensure food self-sufficiency. The

availability of soil maps differs greatly between member states. While the Belgium and Netherlands have complete coverage of 1:50.000 and 1.200.000 soil maps, most other member states have only detailed maps for specific areas.

So far, only few member states have detailed monitoring programs that monitor changes in soil characteristics over time. The monitoring programs that are in practice are diverse in nature; they often reflect specific (local) soil problems and priorities and interests of specific groups.

1.3 Towards an EU soil strategy

Though the vital role of soil in ecosystem functioning and society in the European Union (EU) is well-recognized, there is as yet no EU policy focused on soil protection in general. Various EU policy instruments do influence specific aspects of soil protection indirectly, such as the Common Agricultural Policy, land use policy, the Nitrate Directive, the Water Frameworks Directive, the Air Quality Directive, Waste Framework Directive, the Environmental Impact Assessment Directive, and the Habitat Directive, but there is no integrated and systematic strategy or assessment of their effects.

So far, individual member states have taken various initiatives on soil protection. These various initiatives reflect the different priorities and threats between individual member states. It also reflects the geographical variations in soils and environmental conditions within the EU. These variations also emphasize that any soil policy should have a strong inbuilt local element.

Currently, there is growing awareness that the functioning of soils in the biosphere and the effects of soil degradation not only have local but also have global consequences. The multifunctional nature of soils and the need to preserve the sensitive balance between soils, groundwater, surface waters and atmosphere have provided the grounds for the need of EU-wide approaches to soil protection. It is believed that such concerted approaches are most likely effective.

The growing awareness in the EU that the soil resource needs to be protected for sustainable development is reflected in part in the 6th Environment Action Program 'Our Future, Our Choice', which states that a thematic strategy for soil protection should be established. The Soil Protection Communication released in 2001 was the first step in the process of establishing such a broad EU thematic strategy for soil protection. The aims of the Soil Protection Communication have been listed as follows:

- identify the characteristics of the soils that are relevant for policy making
- describe the vital and multiple functions of soils
- identify the main threats to soil and the need to tackle them
- present the state of play of soil information and monitoring in the EU and identify data gaps which need to be filled as a basis for soil protection policy, and

- establish the policy frame for Community actions for soil protection and present some concrete proposals for action including an EU soil monitoring system.

Currently, a number of EU thematic working groups and task groups are preparing arguments, suggestions and recommendations for setting up a common EU soil strategy for soil protection, monitoring and research agenda. Such an EU soil strategy should foster sustainable development and harmonize policies. On the other hand an common EU soil strategy should not frustrate current national policies and/or saddle individual member states with unrealistic targets.

1.4 Objectives of current report

The general objective of the current report is to provide a quick overview of the soil status of the rural area in the Netherlands. The report specifically addresses the topics and soil threats to be addressed in Soil Protection Communication and in the forth-coming EU soil strategy, notably soil erosion, soil contamination, soil sealing, soil compaction, soil organic matter, soil biodiversity, soil salinization. For each of these topics the general soil status and the deviation from the 'optimum situation' are described. Where possible the geographic distribution of threats is indicated in a quantitative way. When insufficient data are available to provide such a geographic distribution, a more qualitative overview has been presented and the lack of data and information has been indicated.

A second objective of the study was to identify topics, subjects, areas and views where opinions and concerns about the soil status differ among scientists. This second objective reflects the wish of the customers, the Ministries of LNV and VROM, to have a clear cut indication whether the status of the soil for the various topics should be judged as a major concern or not, from the perspective of the forthcoming EU soil strategy. However, there is as yet no well-established framework, reference values, and yard-sticks for this judgement, as the objectives and targets of the EU soil strategy have not been defined. Hence, the contributors to this report were also asked to present their personal views and to indicate whether the soil status should be considered as a concern or not. It must be taken into account that different people have different perceptions and concerns, which reflect different attitudes towards the potential of technical solutions, social and institutional flexibility, and stability and resilience of natural systems (e.g., Van den Berg & De Mooij, 1999). Clearly, the second objective of this study appeared to be difficult to achieve fully. Many persons (scientist and policy makers) have contributed and commented on draft versions of this report. The editors tried to include these various contributions and comments as much as possible, but there is a trade-off between completeness of views and opinions on the one hand, and the readability of a report on the other hand.

The study focuses on the rural area only. By far the greater part of the rural area in the Netherlands is agricultural land, intersected by small nature conservation areas, surface waters, and forests. Hence, this study focuses mainly on the soil status of

agricultural land. The soil status of urban, industrial and infra-structural areas, and waste dump sites are not included in this study.

There are close links between soil quality and water quality (groundwater en surface waters). This is especially the case in lowlands like the Netherlands. The EU Water Framework Directive encompasses many Directives, including the Nitrates Directive and Groundwater Directive, which specifically deal with water quality. These Directives directly and indirectly also set targets for soil use and soil management, and thereby affect soil quality. However, this study does not address these linkages in policy and the possible need for more integration.

Other aspects not addressed by this study for reasons of lower priority include:
effects of land use changes; lowering of the soil surface due to oil and gas exploration, the quality of the sub soil (deeper soil layers beyond rooting depth); groundwater; coastal areas; dune migration; and aspects related to soil and cultural heritage.

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2 Soils in the Netherlands

O. Oenema

2.1 Unique environmental conditions

Unique to the soils in the Netherlands is the man-made character, its wetness, its high (natural) soil fertility level and its intensive use. These unique features must be kept in mind for understanding soil quality and for understanding the changes in and possible threats and concerns for soil quality. Understanding current soil quality is equivalent to understanding the history of the soil (soil formation) and its use. Agriculture has played a dominant role in (re-)shaping soils in the Netherlands, and understanding changes in soil quality is therefore also equivalent to understanding past and present agriculture practices. Changes in land use and agriculture have been a major driving force for the current state of and pressure on soil quality.

2.2 Living in a delta

The Netherlands is situated in the delta of the rivers Rhine, Meuse, and Scheldt. The western and northern half of country has riverine and marine deposits of predominantly clay-rich material. The eastern and southern half of the country is covered by wind deposits. These predominantly sandy deposits originate also from riverine and marine deposits. Peat deposits have been formed in lower lying areas in between and at the border of the riverine and marine deposits. Almost all soils at the surface are recent deposits (not more than 10,000 years).

Though almost all soils are drained artificially, large areas are wet or wet in part of the year, due to the high groundwater and surface water levels. The agricultural land is intersected by some 600,000 km of ditches and canals. As a consequence, there is a strong interaction between soil and groundwater and surface waters. This makes soils and land in the Netherlands rather unique, compared to most of the other countries in EU. The wetness makes the soils also fragile. It makes the soil fragile for disturbance, for loss of part of its functions.

2.3 Human alterations

The clay and peat soils in the western and northern half have been reclaimed from the sea and lakes and are situated in a polder-like landscape. These soils are artificially drained via trenches, ditches and subsurface drains. They have been cultivated and manured for centuries. They have been enriched with nutrients, especially with immobile nutrients like phosphorus and some trace elements. They are highly productive, because of the high soil fertility level, the favorable climatic conditions and the high management skill of the farmer.

The natural (native) fertility of the sandy soils in the east and southern half was rather low. The century-long transfer of biomass and residues from common grounds to private grounds in traditional farming practices have created a patchy distribution of enriched man-made plaggen soils and depleted common grounds in these areas. This farmers´ practice has contributed to the high landscape diversity and biodiversity that existed prior to the era of modern farming. Farmers´ practice in the 20th century has strongly diminished this diversity by manuring, reparceling, leveling and drainage. As a result, current characteristics of sandy soils witness a very strong anthropogenic influence. Most soils are highly fertile and intensively managed nowadays.

The fertile, men-made soils are one of the cornerstones of the high production level of the export oriented agriculture in the metrapool of the Rhine-Meuse-Scheldt delta (Bieleman, 1992, 2000). There are only few other places in the world where the human alteration of soil is so large, and these other places are also found in deltas along rivers in for example China, Vietnam, Egypt and Irak. Extreme alterations of soil in intensive agriculture include ploughing of land two meters deep to bring virgin soil of wanted soil texture to the surface for growing bulbs, and substrate culture in glasshouses and in outside horticulture and ornamental culture. The area of such cultures has increased during the last decades to a few ten-thousands ha.

2.4 Pressures on soil quality

Many of the pressures on current soil quality have their origin in part in the history. Salinization of soils and groundwater, arsenic in groundwater and surface water, acid sulfate soils, soil wetness are for the greater part related to intrinsic characteristics of the soils and its environment, though there is also human influence. Other pressures find their origin predominantly in the current land use and soil management. These pressures include soil erosion, soil organic matter decline, soil pollution and acidification, and soil compaction and structure deterioration. All these pressures may lead to a change of the state of soil quality and hence to a change in ecosystems services.

2.5 Spatial distribution of soil types.

Soils in the Netherlands are usually classified on the basis of its texture (sand, load, loss, clay), organic matter content (mineral versus peat soils), wetness or groundwater water level (dry, medium wet and wet soils, or well-drained, moderately well-drained and poorly drained soils). Soils can be classified according to the origin (marine, riverine or fluviatile, eolian, and glacial deposits), and age (recent, old) of their parent material. Next, soils can be classified on the basis of the dominant soil forming processes (e.g., entisoils or vaaggronden, podsols, man-made plaggen soils, etc.). This diversity in classification possibilities gives a diversity of possible soil maps, and all of these maps have their value in explaining the spatial distribution of soil types, properties and characteristics.

Figure 1 shows the common soil map of the Netherlands. Marine clay soils are found in the north, west and central part of the country. Sand soils are found in the east and south, and peat soils are found in a scattered pattern in between the clay and sand soils, with most of them in a band that stretches from the northeast to the southwest.

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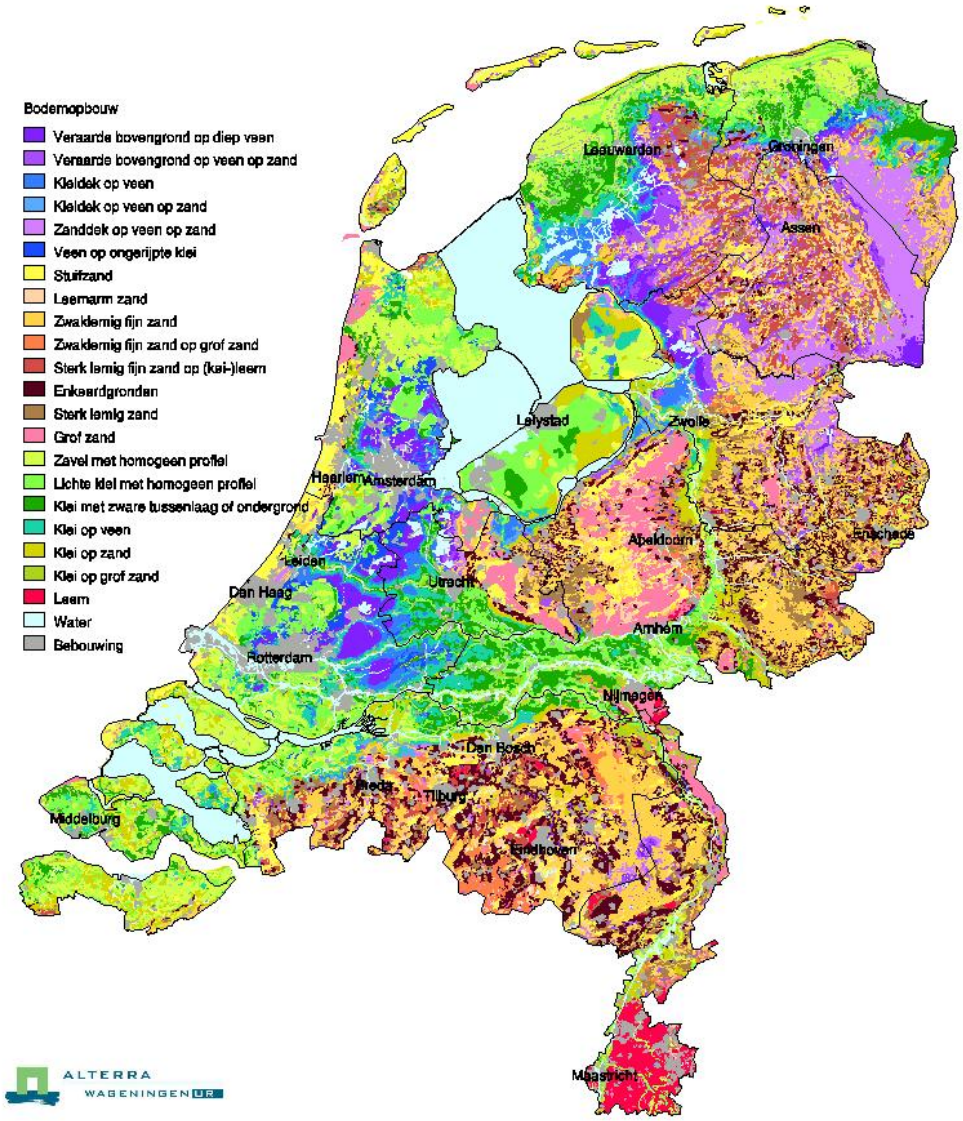

Figure 1. Soil map of the Netherlands (source: Soil map of the Netherlands, scale 1 : 50.000 © Alterra).

3 Soil Organic Matter

P.J. Kuikman

3.1 Introducing the subject

Soils are a huge store of carbon (C). The current pool of soil organic carbon in the world has been estimated at 1500 Pg, i.e. approximately 2 times larger than the total amount of C in the atmosphere and nearly 3 times larger than the amount of C in terrestrial vegetation. The current pool of soil inorganic carbon in the world has been estimated at 1700 Pg, predominantly in the form of calcium carbonates ($CaCO_3$). However, this chapter only deals with soil organic carbon (SOC)[1].

All organic carbon in soil has been derived from plants that synthesize atmospheric CO_2 with the help of solar energy into carbohydrates. On a global scale, the terrestrial vegetation fixes about 120 Pg C per year. About half of this amount is respired directly by the vegetation it self as CO_2 into the atmosphere again. The other half accumulates temporarily as litter, residues and soil organic matter, but is also respired and returned as CO_2 into the atmosphere again in the course of time. Evidently, there is a huge annual exchange of CO_2 between atmosphere and biosphere; approximately half of the return of CO_2 into the atmosphere proceeds via the soil. Soils, therefore, play an important role in the global C cycle.

The increase in atmospheric CO_2 since the 1850s has been attributed to two principal human activities, i.e., land use changes (currently about 1.6 Pg C per year) and fossil fuel combustion (currently about 5.5 Pg C per year). Approximately 3.3 Pg C per year of the 7.1 Pg C that is currently emitted into the atmosphere ends up as (increased concentrations of) atmospheric CO_2, 2.0 Pg C per year ends up in oceans, 0.5 Pg C per year ends up in forests in the northern hemisphere and an estimated 1.3 Pg C per year is related to an unknown or missing terrestrial sink, which is likely in the terrestrial biosphere. Hence, the role of soils in C sequestration is relevant.

The amount of SOC depends on current and past land use, soil management practices, soil texture and climate (e.g., Jenny, 1948; Bakken, 1994). Land use changes may cause large and rapid changes in land cover and stocks of SOC. In general, SOC declines following conversion of pasture (grassland) to cropland or plantations (see meta-analysis by Guo et al., 2003). There is delicate equilibrium in soils between input and output of organic C. The level of this equilibrium and hence SOC content depends on soil texture, land-use, climate, and soil management. Soils with low SOC content will accumulate organic matter until the equilibrium SOC content (input equals output) has been reached. Similarly, soils with high SOC content will loose organic matter until the equilibrium SOC content (input equals output) has been reached, again depending on local soil texture, land-use, climate, and soil management. The establishment of an equilibrium SOC level following a land use

[1] 1 Pg is 10^{15} g; 1 Tg is 10^{12} g; 1 Gg is 10^{9} g and 1 Mg is 10^{6} g.

changes takes approximately 50 to 150 years. The long period needed for establishing an equilibrium, combined with the rather frequent changes in land use, indicates that few soils have equilibrium SOC levels. Equilibrium SOC levels will only be found in old (>100 years) permanent grasslands, forests and arable lands.

Organic matter in soils contributes to the biological, chemical and physical soil fertility. SOC contributes positively to water storage capacity, soil structure, nutrient retention and to nutrient supply to plants. SOC also provides substrate and energy to micro organisms, and plays a key role in the environmental regulation of denitrification, nitrate leaching and emissions of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). Hence, SOC is very important for the functioning of the soil in the ecosystem.

3.2 Controls of SOC

The amount of organic carbon in soils depends on:
- Soil type (texture, fertility level) and age
- Past en present land use (cropping systems, including cover crops)
- Soil cultivation and management (ploughing, permanent or annual cropping)
- Hydrology and water management

The amount of SOC strongly decreases with soil depth. The largest amounts are found in the topsoil (0-10 cm). The amount of SOC in the topsoil varies with soil type, from less than 1% in dune soils, to 1 - 2% in light-textured, intensively cultivated, arable soils, to 2 – 5% in heavy textured clay soils used for permanent grassland, to 5 – 20 % in wet grasslands, and to 20 - 40% in peat soils. Usually, clay soils (heavy texture) contain more organic carbon than sand or loam soils (light textured soils), because some of the organic C in clay soils is physically protected from decomposition by micro organisms.

Grassland contains more organic C in the topsoil than arable land, because the amount of organic C returned to the soil is much higher in grassland than arable land, while the rate of decomposition is lower because of much less cultivation. Forests and heath lands often have high SOC levels, because all the biomass and litter produced remains at the site (is not harvested), and most forests and heath lands are situated on poor soils that produce poor quality litter that is not easily decomposed. As a result, poor sandy soils under heath lands and forests often have a thick layer of litter and a high SOC level in the top soil. Peat soils contain the highest stocks of SOC, because the wetness and anaerobic conditions greatly retard the decomposition of litter and residues in peat soils.

Soil cultivation greatly enhances decomposition of organic C because of the effects of aeration and physical breakage of organic residues in soils. The amount of SOC changes upon a change in land use, soil cultivation and climate. An increase in SOC is usually rather slow (up to 1000 kg SOC per ha per year), while a decrease can be fast (few thousands kg of SOC per ha per year. Hence, sequestration of SOC requires

careful planning and management. The time required to reach equilibrium after a change in for example land use or soil cultivation ranges between 50 to 150 years.

Most agricultural soils are not in equilibrium as regards SOC, because land use and/or soil cultivation practices change at shorter time span than the time required for reaching the equilibrium level of SOC. Common changes in land use, and soil cultivation and management practices that affect SOC include:

- a change from grassland to arable land (e.g. for potato and flower bulb growing);
- grassland renovation, leveling and reseeding;
- set aside land;
- changes in crop rotation and cover crops;
- changes in soil cultivation (e.g. depth of ploughing, minimum tillage);
- changes in grazing system (e.g. from rotational grazing to zero grazing);
- changes in type and amount of fertilizer and animal manure;
- changes in drainage and irrigation (water management).

3.3 Amount of organic carbon in soils in the Netherlands

The total amount of SOC in the Netherlands is approximately 285 Tg C in the top 30 cm of all soils under agriculture, forest and nature conservation areas (Kuikman et al., 2003). Peat soils contain the largest amounts (approximately 200-350 Mg per ha), and sandy soils the least (approximately 50-100 Mg per ha). In between the high number for peat soils and the low numbers for some sandy soils, there is a whole scatter of variation. On average, soils in the Netherlands are rich in SOC, compared to other EU-member states. When compared to EU-member states in the south (Italy, Spain, Portugal, Greece, and also France), soils in the Netherlands contain relatively more SOC.

There is no systematic monitoring program for SOC in The Netherlands. As a result, there is no accurate inventory of SOC and of changes in SOC with time. The estimates given above for the total amount of SOC are based on the so called *Landelijke Steekproef Kaarteenheden,* which includes approximately 1500 measurements of SOC. There is also no specific monitoring protocol or program for SOC in the Netherlands. With reference to the Kyoto Protocol, a project proposal has been submitted to the LNV research programme on Basisgegevens ondergrond to define an approach for such a protocol; execution of this work has not started yet.

However, there are large amounts of data about SOC and soil fertility measured in farmers fields by the Laboratory for Soil and Plant Research BLGG at Oosterbeek. These data have been collected in the course of decades, in response to request by farmers to evaluate the soil fertility status of their land. Such data may be used to provide a general overview of the spatial distribution of SOC when coupled to a Geographic Information System. It must be kept in mind however that the depth of sampling varies from 5 to 10 cm for grassland soils and from 20 to 25 cm for arable land. Further, there is no accurate link with soil type characteristics (e.g., groundwater level), past land-use changes and with soil cultivation and soil management practices.

As a consequence, it is difficult to derive from these data accurate trends in SOC in response to changes in land use, soil cultivation and soil management.

Another possible data source is TAGA (technical and soils archive) with descriptions and data on long term field experiments (Kooistra et al., 2003). In the 20th century, there have been many long-term field experiments where relationships were examined between land use, fertilizer management and soil cultivation on the one hand and soil fertility characteristics including SOC on the other hand. However, nearly all these experiments vanished in the 1980s when the believe in computer models surpassed the trust in experimental data from the field (the latter were also regarded too costly). This data source could be explored to examine trends in SOC as function of land use, soil cultivation and soil management.

Figures 2 and 3 shows the spatial distribution of SOC in the Netherlands, based on a compilation of various sources. The distribution of peat soils is evident from their large amounts of SOC.

3.4 Inputs and outputs of SOC

On average, approximately 2% of the SOC is respired each year by micro organisms, i.e., for the Netherlands in total 6 Tg C or 22 Tg CO_2 per year. This translates to on average 3 Mg of SOC per ha per year, when assuming 2 million ha of agricultural land. The greatest part of this loss occurs in drained peat soils. To balance the respiration losses, on average 3 Mg SOC has to be added to the soil via litter, crop and root residues and animal manure. The actual number varies from about 1 to 2 Mg SOC per ha per year for sand and clay soils to 4-10 Mg per ha for peat soils (see also chapter 8).

What are the sources? Velthof (2004) recently made an inventory of all inputs of organic matter to agricultural land. He calculated the inputs of effective organic matter (EOM), i.e. the organic carbon that is not easily mineralized, about equivalent to SOC. The total input was 5.2 Tg EOM, which translates to 3.0 Tg SOC. Major sources of SOC are crop residues in grassland soils (1.1 Tg SOC per year), cattle manure (1.0 Tg SOC), crop residues and cover crops in arable land (0.6 Tg SOC), manure of pigs, poultry and other animals (0.3 Tg SOC per year), and composts (0.1 Tg SOC per year). The average input of SOC is 1.5 Mg per ha per year.

The net balance of inputs and outputs of SOC in the Netherlands suggests that soils are loosing SOC at a rate of about 3 Tg per year. The loss of SOC via mineralization is twice as large as the input of effective SOC via animal manure, crop residues and compost. This result is in line with the large losses of SOC that occur in peat land areas in the Netherlands. For sand and clay soils, the data suggest more or less balanced inputs and outputs.

Figure 2. Carbon stocks in soils in the Netherlands (0 – 30 cm) on the basis of the Soil Map of The Netherlands, scale 1 : 50 000, the Dutch Soil Monitoring (LSK) database and the land cover database of the Netherlands (LNG3) with all soils (left) and soils in arable land (right) (from Kuikman et al., 2003)

Figure 3. Carbon stocks in soils in the Netherlands (0 – 30 cm) on the basis of the Soil Map of The Netherlands, scale 1 : 50 000, the Dutch Soil Monitoring (LSK) database and the land cover database of the Netherlands (LNG3); with soils in grassland (left) and soils in nature areas (right) (from Kuikman et al., 2003)

There are various uncertainties involved in these rough calculations. Decomposition rate was set at 2% of the SOC in the upper 30 cm, while the decomposition usually is calculated on the basis of SOC in the top 20 cm. Hence, out estimated of SOC losses from the top soil may be a little to high. Further, we estimated that the SOC input via crop residues (stubble, roots, and litter) in grasslands at 1.2 Mg per ha per year, but there is considerable uncertainty in this number (which has a huge influence on the total SOC input).

Recent results of NMI (2003) indicate that approximately 30% of the area of arable land is loosing SOC. This estimate is based on similar calculations as presented above, using a mean decomposition rate of 2% of SOC, and calculating the sum of all inputs of effective SOC. Evidently, this calculation procedure assumes that the more SOC is in soil, the larger the decomposition losses and the larger the required inputs of SOC to make a balance. The results are in line with the loss of SOC in the sandy peat soils of the Veenkolonien, where SOC contents have decreased from a relatively high level following reclamation of these former peat land areas to much smaller SOC levels nowadays. This decrease in SOC make these soils more vulnerable to wind erosion (chapter 5) and drought.

In grassland soils there is a large turnover of stubble and roots, which is sufficient to balance the mean respiration losses. Moreover, many grassland soils receive animal manure produced from grass (silage) and maize silage, and from imported animal feed. The grass (silage) and maize silage production in the Netherlands amounts to 5-6 Tg C per year. Approximately 20-40% of the C in this animal feed ends up in manure and is applied to agricultural land. This translates to an average of 1 to 1.5 Tg C per year, and 0.5 to 0.8 Tg of effective organic carbon, as only about 45% of the carbon in cattle slurry is effective organic carbon.

Approximately 10 Tg of organic C is imported each year via animal feed used to feed 100 million chicken, 12 million pigs and approximately one-third of the 4 million cattle in The Netherlands. Again, farm animals utilize and respire a large amount of this C, but a significant fraction (20-50%) ends up in animal manure and is applied to agricultural soils in the Netherlands. Basically, this is a sort of biomass transfer from elsewhere (Asia, Latin America and Northern America) to the Netherlands. Approximately 1 to 3 Tg C from the imported animal feed ends up in animal manure and is applied to agricultural soils in the Netherlands. This translates to 0.4 to 1 Tg of effective organic carbon, as only about 30% (in pig slurry) to 45% (in cattle slurry) of this carbon is effective organic carbon.

The picture for arable soils and soils used for vegetable and bulb growing is different from that of grassland. Firstly, soil cultivation contributes to an enhancement of respiration losses, so that mean respiration losses are relatively high. Secondly, the return of C via litter and crop and root residues is relatively small, especially in crop rotations with little or no cereals and cover crops. Cereals produce large amounts of stubble and litter (straw), which is rather resistant against decomposition, while root crops and leafy vegetables produce little stubble and litter (leafy biomass), which is also easily decomposed. It should be noted also that the average yield level in arable

farming has increased by a factor 2 between 1950 and present, but that the amount of crop and root residues and litter has not much increased, because the harvest index has increased. Thirdly, the ploughing depth has steadily increased from the 1950s. Thereby subsoil with low SOC has diluted the SOC in the top soil. An extreme case in this respect is deep ploughing, where virgin (without pathogens) subsoil with preferable soil texture is lifted to the surface. However, this subsoil often has a low native SOC content. These three factors combined contribute to a steady decline in the amount of SOC in arable land. Farmers try to reverse this trend by including cover crops in the crop rotation, and by applying animal manure and compost. Bottlenecks may exist in special cases, such as growing bulbs on deep ploughed dune soils (Geestgronden), tree nurseries (that export SOC rich top soil attached to the tree), and vegetable growing on sandy and loamy soils sensitive to sealing.

Summarizing, agricultural soils in the Netherlands respire together on average 3 Mg C per ha per year, but there is a large variations between sand and clay soils (1-2 Mg per) and peat soils (4-10 Mg per ha). Estimated total respiration losses appear twice as large as the estimated total input of SOC. This loss of carbon occurs for the greater part in peat soils and reclaimed peat soils, and to some extend also in arable soils. Grassland soils produce a lot of litter, stubble and crop residues and thereby have a relatively high SOC level. In addition, grassland soils receive on average 0.6-1.2 Mg SOC via animal manure which is in part produced from home-produced grass and maize silage, and concentrates imported from elsewhere. Arable soils receive on average much less C via stubble and crop and root residues, while soil cultivation enhances respiration losses. The intensification of crop rotation and soil cultivation has likely contributed to a decline in SOC in some arable soils. Farms try to nullify this trend by applying manure and compost and by growing cover crops. Some bottlenecks do exist in practice, but the questions is whether all cultivation practices should be possible everywhere? Or should soil quality also define which crops and practices are sustainable and which not? There is scope for improving the SOC balance arable land by growing cover crops, minimum tillage and use of manure and composts

3.5 Peat land

Peat soils posses a special position in the national balance of soil organic carbon (SOC). One the one had they store the largest amounts of SOC, but on the other hand they contribute most to the total annual loss of SOC. Currently, the Netherlands has about 200,000 to 300,000 ha of peat lands (see also chapter 8). The thickness of the peat layer ranges from 0.4 m (the minimum thickness in the top 0.8 m for a soil to be classified as peat soil) to more than 10 m. A spatially explicit database on thickness and amounts of SOC in peat soils in the Netherlands does not exist, and an accurate estimate of the amount of SOC in peat soils can not be given.

Currently, the oxidation of peat produces substantial amounts of CO_2 (estimates range from 5 – 15 Mton CO_2, which is about 5% of the total CO_2 emissions in the

Netherlands). Furthermore, these soils produce also large amounts of the powerful greenhouse gas nitrous oxide (N_2O). The water management as currently practiced is crucial for agriculture and the settlements in this region, but on the other hand is a disaster for the remaining stores of carbon in these soils and the emissions of CO_2 and N_2O.

There are many trade-offs associated with changes in groundwater level in peat land areas (see also chapter 8). Lowering the groundwater level has a direct economic benefit for agriculture, but it has the longer term effect of subsidence, which is detrimental to both agriculture, infra-structure and the environment. Lowering the groundwater level has positive effects on bird life, but negative effects on biodiversity of the vegetation. Lowering groundwater level increases eutrophication of surface waters and the emission of greenhouse gases into the atmosphere. Current policy is to monitor the rate of subsidence and to manage the water level at local scale (spatially different levels), which is as yet not a sustainable solution for the longer term.

3.6 Ploughing-down grasslands

Grasslands contain the second largest stock of SOC, after peat land areas. Especially old permanent grasslands contain a lot of SOC. The current area of grassland is about 1 million ha; the area has steadily decreased from about 1,4 million ha in 1950 as a result of the conversion of grassland into maize land (approximately 0.25 ha) and because of the conversion of agricultural land into urban, industrial and infra-structural areas.

Approximately 10% of the grasslands are renovated each year (all grassland once every 10 years). Approximately 5% of the grassland is transformed temporarily to cropland, in response to the request by arable farmers for virgin land free of pathogens to grow potatoes, bulbs and flowers. Either way, the organic matter contents decline rapidly upon ploughing down the SOC rich sod and top soil, because soil cultivation accelerates the decomposition of SOC. This ploughing down of grasslands contributes significantly to the emissions of CO_2 and N_2O from agriculture. Figure 1 shows the release pattern of emissions of CO_2 and N_2O from grasslands ploughed down between 1970 and 2020. Between 1970 and 1990, a large area of grassland was converted into maize land, giving a peak in emissions of CO_2 and N_2O. Figure 1 also indicates that the emissions of CO_2 and N_2O continue far after 2020, though at a lower rate. All together, the results point at the important role of grassland ploughing to the loss of SOC and to the emissions of CO_2 and N_2O from agriculture

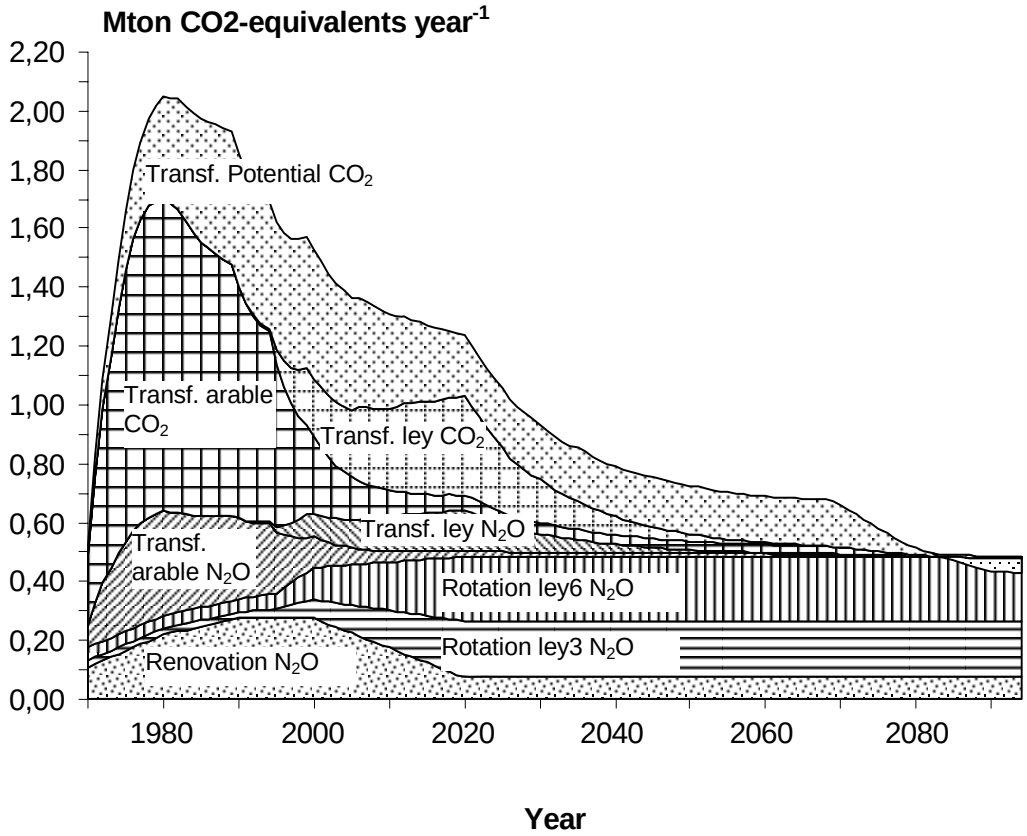

Figure 4. Calculated long-term emissions of CO_2 and N_2O (expressed in CO_2-equivalents) following the ploughing down of grasslands for various purposes, in the period 1970-2020. A distinction has been made between ploughing leys in rotations, ploughing to renovate permanent grassland, and ploughing permanent grassland for arable cropping (maize) and ley systems. Emission are split up for CO_2 and N_2O, and in ploughing between 1970 - 2000 for maize and between 1995 and 2020 for ley rotations. A possible grassland ploughing before 1970 and after 2020 has not been incorporated in these calculations (Vellinga et al., in press 2004).

3.7 Conclusions

On average, soils in the Netherlands are relatively rich in SOC. Most SOC is in peat soils and least in sandy and loamy soils. The balance of SOC inputs and SOC outputs suggests that there is a significant net loss of SOC in agricultural soils in the Netherlands. Drained peat soils contribute by far the largest amount to this loss of SOC. Only permanent grasslands likely gain SOC.

This loss of SOC significantly contributes to the emission of greenhouse gases in the Netherlands (2-5% of the total national emission). This however is not reported in our National Inventory Report despite a binding international commitment.

Land use and land use changes have a dominant influence on SOC. High SOC levels are found in soils under permanent grassland, and relatively low levels in arable land intensively used for growing root crops and vegetables.

The total supply of C in grasslands and most arable lands is sufficient to balance mean respiration losses in soils in the Netherlands. A significant fraction of arable land is currently loosing SOC, because inputs of effective SOC do not balance the respiration losses of SOC. The SOC balance can be improved on at least some arable land by using cover crops, minimum tillage and application of effective SOC. The current distribution of crop residues, stubble and animal manure is uneven, with much more C applied to grassland than to arable land.

Local bottlenecks with too low levels of SOC may occur in specific cases with demanding farm practices. The question remains whether such practices are ecologically sustainable on the long term.

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4 Soil pollution

4.1 Heavy metals

P.F.A.M. Römkens

Heavy metals in soils can be divided roughly in two categories, essential elements and non-essential elements. Essential elements include Cu, Mo, Cr and Zn, non-essential elements include metals like Pb, Cd, Hg, and As (by definition, a metal or metalloid in case of As is considered a 'heavy' metal when the specific density exceeds 5). A major difference between the two groups is that crops need a certain amount of Cu, Zn and Mo to grow. However, when the supply becomes too large, the effects of these metals to plants change from beneficial to toxic. As of now, no benefits are known to plants for the ´non-essential elements´. Effects of high concentrations of heavy metals in both arable cropping systems and natural ecosystems include direct (fyto)toxicity, carcinogenic effects, or specific impact on organs like kidney (Cd) or nervous systems (Pb). Leaching of heavy metals to groundwater and surface waters can contribute to effects on aquatic organisms.

The level of metals in soils is related to both soil type and land use. As outlined in chapter 2, soils in the Netherlands are predominantly sedimentary soils, derived from wind, water or glacial deposits. The natural background level of heavy metals in these soils depends therefore on the origin of the sediment. In general sandy soil have lower 'background' level compared to clay and peat soils, even without considering the difference in binding capacity which makes that metals accumulate more easily in both clay and peat soils. In general, the natural background level of most elements is lower in sediments than in volcanic parent materials. A summary of the variation in the content of heavy metals in peat, sand and clay soils is presented in Annex 1 to this report.

Depending on the intensity of the land use, the level of most metals has increased in the uppermost part of agricultural soils (5 to 40 cm). Continued applications of animal manure, fertilizers and composts have contributed to an enrichment of the top soil with some heavy metals.

In specific areas such as the Kempen the impact of (neighboring) land use (in this case input from zinc melting activities) goes beyond the surface horizon and heavy metals levels have increased throughout the soil profile to a depth of about 1 meter. Here, approximately 35,000 ha of agricultural land has a Cd level > 1 mg kg^{-1}. Other areas where heavy metal levels have increased far beyond background level in the whole soil profile include the floodplains of the major rivers Rhine, Meuse, Scheldt and IJssel. Approximately 36,000 ha along these rivers is prone to regular flooding. About 70% of these flood plains are used as agricultural land, mainly as grassland. Also along smaller rivers like the Geul and Roer (10,000 ha, of which 2,500 ha is used for arable crop production) and in river sediments originating from the Dommel in the Kempen have heavy-metal polluted soils. In these sedimentary soils,

heavy metal levels are high because of deposition of contaminated sediments from elsewhere. Fore example, sediments from the Rhine and Geul originate from Germany and Belgium. In some cases, the accumulation of metals in soils is from contaminated groundwater (e.g. in the Kempen).

In the river floodplain soils, heavy metal levels are often in excess of current 'Intervention values' that are used as criteria for clean up. For the Kempen area, it has been estimated that there are up to 750,000 m^3 contaminated sediments in small rivers. Further, approximately 18,000 ha of peat soils in the western part of the Netherlands (Veenweide gebied) which have received household waste for centuries, also contain elevated levels of metal (especially Pb and Cu). Together, approximately 100,000 ha of agricultural land can be considered as polluted due to diffuse inputs (5 % of the total area of agricultural land).

Figure 5 shows the spatial distribution of the cadmium (Cd) content in soils. Hot spots (red and orange colors) are found in various regions, notably in peat land areas, and De Kempen. Low Cd contents (blue and green colors) are found in nature conservation areas.

Changes in the input of contaminants to soils in the period 1990 to 2001 are presented in Table 1. The data indicate that inputs have decreased strongly between 1990 and 1995 but remained virtually unchanged after 1995.

Table 1. Total inputs of contaminants (elements) to soils in the period 1990-2002, in tons per year per year. Excess load (last column) is the difference between estimated total input and total output. Source: Milieumonitor 2003, CBS 2003)

Contaminant	1990	1995	1999	2000	2001	Excess load
Arsenic (As)	0.9	0.3	0.3	0.3	0.3	Na
Cadmium (Cd)	6.3	3.1	3.1	3.1	3.1	2.5
Chromium (Cr)	59.3	57.9	60.3	61.0	61.6	54.5
Copper (Cu)	898.6	726.8	738.3	721.4	731.8	400
Mercury (Hg)	0.146	0.014	0.013	0.013	0.013	0.24
Lead (Pb)	497.3	333.6	323.0	318.9	319.7	56.6
Nickel (Ni)	27.1	26.4	27.5	27.7	28.0	52.1
Zinc (Zn)	1793.7	1680.7	1803.1	1744.8	1763.4	1099

Major contributors to the loading of soils include animal manure and fertilizers (for Zn and Cu more than 90% of total emission), trade and industry. Inputs to agricultural land are via application of animal manure (mainly Cu and Zn) and phosphate fertilizer (Cd). Due to spatial heterogeneity it is, however, difficult to assess the magnitude and dynamics of the increase in the heavy metal content in soils. Most analyses according to the balance approach indicate that accumulation still occurs. Recent estimates suggest that on a national scale inputs to agricultural land still exceed outputs (Table 1; CBS, 2003). The data in the final column of table 1 are indicative amounts of metals that accumulate in soils (difference between total input and total output from soil). Estimates of the total inputs and/or total outputs for mercury and nickel are flawed, because the total excess load for these elements is larger than the estimated total input.

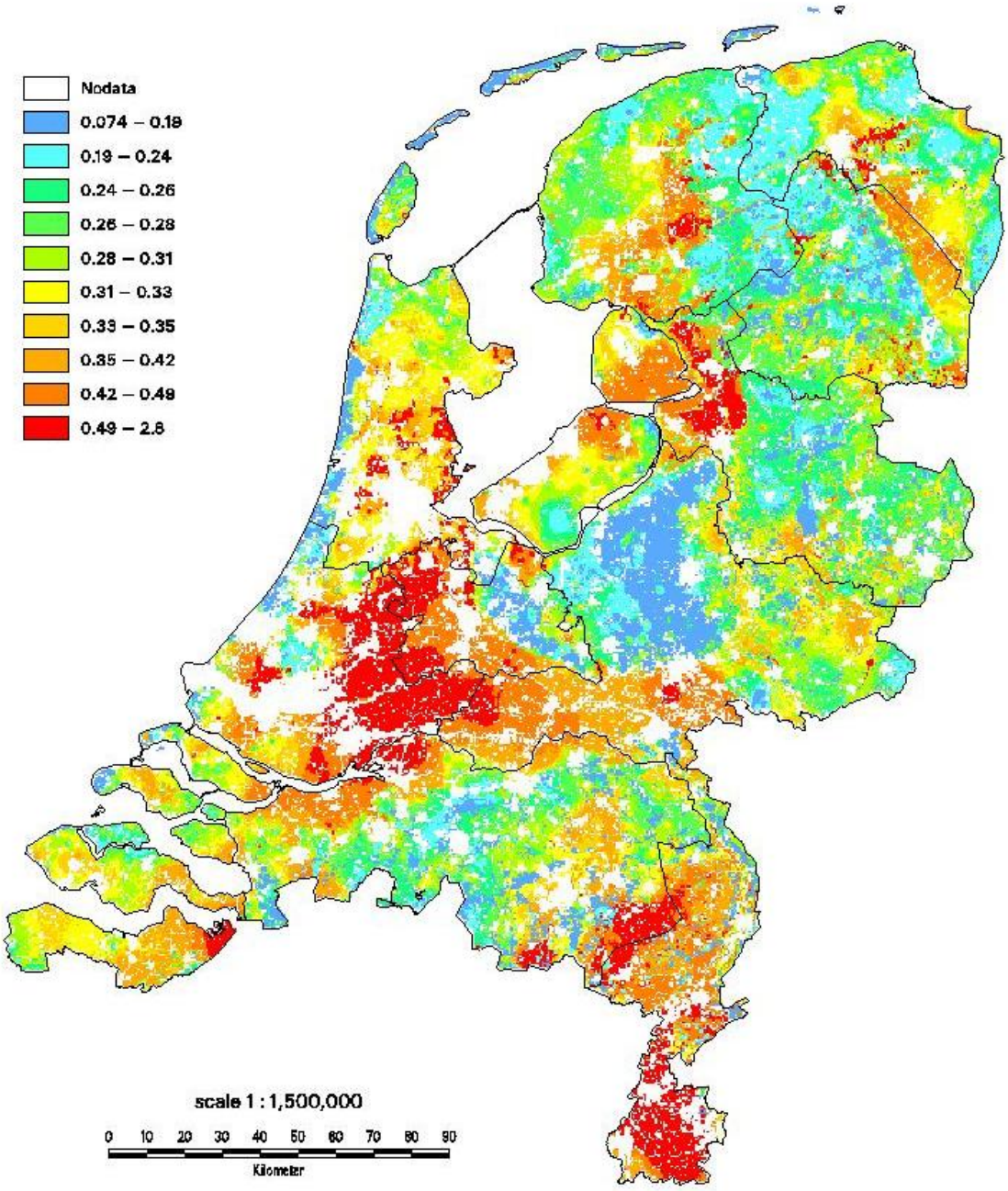

Figure 5. Estimated content of cadmium in soils in the Netherlands (Brus et al., 2002)

The data presented in Table 1 are national data and mask possible differences between soil- and land use types. For example, net accumulation rates in clay soil are larger than those in sandy soils at similar total input levels. Due to a higher soil pH en larger binding capacity, metals are strongly retained in clay soils. Conversely, metals are readily removed from sandy soil via leaching and crop uptake. For proper evaluation of the input - output balance, land use, soil type and hydrology have to be taken into account. Currently, net accumulation rates range from net depletion to accumulation (De Vries et al., 2002) depending (mainly) on soil pH and organic

matter content. Although current input levels have not yet resulted in wide spread areas where heavy metal contents exceed current target values, certain combination of land use and soil type have resulted in elevated metal contents (> 20% of the area exceeds target value). This includes As and Hg in soils used for bulb growing in coastal areas, Pb, Cu and Zn in peat soils (application of Toemaak), Cd and Zn in the Kempen area as well as in the loess area in Limburg (due to atmospheric deposition, van Drecht et al., 1996).

Current estimates indicate that leaching and run-off from soils contribute significantly to the total load of metals into surface waters. Between 11% (for lead) and 50% (for Cd and Zn) of the total load of metals in surface waters is thought to originate from soil (Römkens et al., 2003). This is in agreement with measurements of the quality of surface waters by Water Authorities (Waterschappen). Frequently, levels of especially Cu, Zn and Ni in surface waters exceed threshold levels (MTR) in non-industrial areas. This stresses the need for a better insight in the relation between sources (inputs), pathways (processes in soils and transport) and concentrations in target systems (groundwater, surface waters). Recent data suggest that decreases in inputs of metals in agricultural soils that are prone to leaching, such as acidic sandy soils, will not result in large and direct improvements in surface water quality, as many of these soils still have a relatively large stock of metals.

The loading of soils with heavy metals has also resulted in a measurable increase in the heavy metal content in the upper groundwater (Fraters et al., 2001, Rietra et al. 2003). Concentrations of metals like Cd, Zn, Ni in groundwater are higher in the southern sandy areas than in sandy areas in the northern part of the country, due to higher inputs via atmospheric deposition and animal manure. Also a clear relation between the age of the groundwater and the heavy metal content has been established (Rietra et al., 2003) with high metal concentrations in young groundwater bodies and lower values in older ones. This suggests an ongoing increase in concentrations of metals in groundwater due to acidification of the upper groundwater and increased loading of the soil.

Repeated application of sewage sludge on land results in a considerable increase of the total metal content. It is expected that target values can be exceeded within 50 years when sewage sludges are applied regularly (van Dijk et al., 1998).

Heavy metal contents in soil also affect crop quality. For most metals, uptake by arable crops is limited (e.g. Cu, Pb, As, Hg) but for Cd, quality criteria as defined by the Law on Food Quality (Warenwet) are exceeded on sandy soils throughout the Netherlands as well as on the loess soils in Limburg (approx. 20,000 ha.). Especially in the Kempen area, the quality criteria for wheat are often exceeded. However, the majority of fodder and wheat grown in this area is meant as cattle food, and criteria for food for cattle are less strict (1 mg kg^{-1}). Also for Pb, quality criteria for wheat have been exceeded throughout the Netherlands, especially since the maximum allowed Pb content has been decreased from 0.5 tot 0.2 mg kg^{-1}. However, reliable data on the Pb content of wheat and other arable crop products are scarce as

national inventories have been conducted between 1979 and 1985 when Pb emission rates by traffic were substantially higher compared to current rates.

In the Third National Environmental Policy Plan, the goal has been set to have a national overview of the soil quality in the Netherlands by 2005. This will also provide a quantitative overview of sites with serious soil pollution, and the effort needed to remediate these sites. Current target is that all problem sites are under control within 25 years from now. .

The ecological impact of soils with too high contents of metals differs from site to site. These areas require risk based land management, which still has to be developed and implemented. Soils with high metal contents used for arable land are a risk for food safety. Soils with high contents of metals and/or P obstruct nature development and obstruct also the progress of the reconstruction of rural areas towards more sustainable development.

Conclusions:

- Approximately 100,000 ha of agricultural land can be considered as rather heavily polluted with heavy metals due to a steady excess input of these metals from diffuse sources (animal manure, fertilizers, sewage sludge, composts, flooding, and atmospheric deposition). This area represents 5 % of the total area of agricultural land.
- There is a slow but steady increase in total metal content in agricultural soils. The stand still principle will be hard to realize for many metals. Important sources are animal manure, fertilizers and (locally) sludge and compost.
- It has been estimated that the content of Cd (and possibly Pb) in wheat grown on sandy soils in the Kempen and the loess soils in Limburg frequently exceeds the food quality criteria, but the wheat is supplemented to the animal feed, which has less strict target values than human food.
- Concentrations of metals in shallow groundwater have increased because of leaching from the topsoil, especially in sandy soils used for intensive agriculture.
- Leaching of heavy metals from soils to surface waters is a major source of metals in surface waters. In many cases, MTR criteria are not met (especially for Cu, Zn and Ni). In certain cases, there is a direct link with land use, and application of animal manure

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4.2 Nutrients

O. Oenema

There are 14 nutrient elements known to be essential for plants and 18 for humans and animals, but the emphasis is often on nitrogen (N) and phosphorus (P). These two nutrients are the main crop-yield-limiting nutrients. These nutrients are also dominant in limiting algae productivity and thereby in eutrophication of surface waters. As a result, N and P have a tremendous impact on food production and on the natural environment, at regional and global scales.

When the availability of N and P in soils is low, crop yield and quality are low and the functioning of crops is poor. When the availability of N and P is high, crops yields are high (when there are no other crop-yield limiting factors, such as drought, pests, etc.). However, abundant availability of N may decrease crop quality and increase disease incidence. Abundant availability of N also leads to increased N losses to the wider environment, to the atmosphere via emissions of NH_3, N_2, N_2O and NO_X, to groundwater via leaching of predominantly nitrate and to surface waters via leaching, run-off and erosions of all kinds of N species. Abundant availability of P in soils has little influence of crop quality and disease incidence, but leads to increased P losses to groundwater and surface waters via leaching, erosion and run-off.

In surface waters, low availability of N and P leads to low algae productivity and hence to clear waters (when sediment load is low). High availability of N and P leads to abundant grow of algae, and to ecosystem simplification (monocultures of one or a few species). This enrichment of surface waters through the abundant availability of

N and P leads to a sequence of (negative) effects (dramatic changes in the food web, poor water quality, dead water, bad odor, etc.), which is termed eutrophication. The simplification and degradation of the aquatic ecosystems is because some species can out compete all other species when the availability of N and P is high. As a result, a high availability of N and P leads to a low biodiversity.

Nitrogen and phosphorus in soils

Soils contain roughly between 0.05 to 0.5 % of both N and P. This translates to 1,000 to 10,000 kg of both N and P per ha in the top 25 cm of soil. The contents of both N and P strongly decrease with depth. Hence, most of the N and P are in the top 25 cm. Most (~99%) of the N in soil is organically bound, and only a small fraction (~1%) is dissolved inorganic N, which is available to uptake by plants and micro-organisms and to leaching to groundwater and surface waters. Most (50-90%) of the P in soils is inorganic and bound to iron and aluminum oxy-hydroxides. The other part (10-50%) is organically bound. Only a tiny fraction (<<1%) of total P is dissolved P and directly available to uptake by plants and micro organisms. The total N content in the soil is strongly related to the soil organic matter content (and not to past N fertilizer application), while the total P content is mainly related to the history of animal manure and fertilizer P fertilizer applications.

The mechanisms that release N and P from bound species to dissolved species in the soil control the availability of N and P to plants and the wider environment. These mechanisms are greatly different for N and P. Release of N is mediated by micro organisms that mineralize soil organic matter and the C to N ratio of the organic matter. Release of P is for the greater part controlled by physico-chemical processes and only for a small part by the mineralization of P from organic matter. However, wet soil conditions facilitate micro organism that mediate the release of phosphorus bound to iron hydroxides. In general, the larger the total amount of N and P, the larger the amount of dissolved inorganic species and the greater the availability.

All clay and peat soils in the Netherlands have relatively high native N and P contents. Total amounts of N and P in soils are in the middle of the range of 1,000 to 10,0000 kg per ha given above. Total N is relatively low in sandy soils like dune soils, but also in some intensively managed sandy soils used for arable farming, horticulture and maize silage. Total N is high in organic matter rich soils like eutrophic peat. Total P is low in unmanured sandy soil, like those in nature conservation areas and some forests. Total P is very high in heavily manured and fertilized soils, especially in the east and south of the country.

Monitoring changes in soil N and P

There are no accurate estimates of changes in the amount of N and P in soil, because there is no systematic monitoring program for it. Long-term field experiments that have provided the basic data for fertilizer recommendations, have almost all vanished in the 1970s and 1980s because of changes in research topic and budget cuts in agricultural research. Some trends can be derived from analyses of soil fertility evaluation of farmers' field, carried out by BLGG (Bedrijfslaboratorium voor Grond- en Gewasanalyse) and other service laboratories. However, these analyses have not

been carried out systematically (less than 50% of the farmers do a regular (4 years) analysis), and the results can not be related easily to individual farmers practices. Hence, the cause – effect relationship can not be analyzed easily. Some trends can also be derived from incidental inventory studies at regional or national levels, carried out by various institutes, universities, and service bureaus. Also these studies lack the systematic monitoring over time. (Please note that small changes in the amounts of N and P in soils can not be measured accurately, due to the large spatial variability of N and P contents in soil, and the difficulty of taking a representative sample).

Nitrogen balances

In the 20th century numerous field experiments have been carried out to assess the effectiveness of fertilizers, animal manure and composts in improving crop yield and crop quality. In arable farming, usually not more than 50% of the amount of fertilizer N applied is recovered in harvested biomass. The apparent recovery of N from animal manure in harvested crop is only about 30%, because a significant fraction of the N in the manure is organically bound and not directly available. Almost all N in excess of the amount that is taken up by a crop is lost to the wider environment. Only when the N is applied in the form of compost or manure, a significant fraction accumulates in soil as organically bound N by the compost in the soil, and may become available to crops in subsequent seasons.

Grassland can effectively scavenge applied N from the soil and the apparent recovery of fertilizer N can be as high as 70 to 90% in mown-only grassland. In grazed grasslands, the apparent recovery of applied fertilizer is much lower, because of grazing losses and because the grazing animals return 80 to 90% of the N in taken up with the grazed herbage via the excretion of urine and dung.

Until the 1980s N balances were sparsely used by researchers only. Until then, main emphasis was on crop yield and quality and the effectiveness of fertilizers and animal manure. Most balances were partial balances, i.e. the fate of the N recovered was not measured. From the 1980s onwards, N balances were increasingly used by both researchers, policy makers and farmers. The implementation of the N and P accounting system MINAS at farm level in 1998 highlights the importance of nutrient balances as monitoring instrument for policy makers and as management instrument for farmers. Especially farmers with crop and animal production (e.g. dairy farmers) find nutrient balances instrumental in optimizing the nutrient use efficiency at farm levels (RIVM, 2002, 2004).

Nutrient balances are also instrumental for providing insight in the long-term nutrient use efficiency at national scale. Between 1950 and 2000, the cumulative N surplus of agricultural land has been estimated at about 22,000 kg per ha for each of the 2 million ha of agricultural land in the Netherlands. Essentially all excess N has 'disappeared' into groundwater, surface waters and atmosphere. Some soils may have retained some N from manure and compost in the soil, but other soils have faced a net loss of soil N due to increased soil cultivation (see also chapter 3 about soil organic matter). The net result is that most likely less than 1% of this surplus has accumulated in the soil. It should be kept in mind that accurately measuring a change

of 200 kg of N in the top 25 cm of soil is not well possible, unless in a systematic monitoring program where the same sites are measured on a regular basis and changes can be derived from estimated trends.

Phosphorus balances

The apparent recovery fraction of fertilizer P in the first year is usually 10 - 15% of the amount applied. In subsequent years crops take up between 5 to 1% of the residual fertilizer P. The apparent of P from animal manure and composts is usually equal to or somewhat lower than that of P fertilizer. Almost all P applied in excess of the amount taken up by a crop is retained by the soil, independent of the form of P applied. Leaching losses of P are usually small (about 0.5 kg P per ha per year) unless the total amount of P is very high relative to the retention capacity of the soil, in combination with a high groundwater level.

Between 1950 and 2000, the cumulative P surplus of agricultural land has been estimated at about 2000 kg P per ha. As little P is lost via leaching, soils have accumulated on average 2000 kg P per ha in this period. (Please note that amounts of P in agriculture are often expressed in terms of P_2O_5. A quantity of 1 kg P_2O_5 translates to about 0.44 kg P, while 1 kg P translates to 2.29 kg of P_2O_5. Hence, a quantity of 2000 kg P translates to about 4600 kg P_2O_5 per ha).

The accumulation of P in soils has been unevenly distributed over the agricultural area. Some soils received double or triple the average surplus. Other soils though received essential no surplus, and are still low in available P. The area of low P soils in the Netherlands is only 1% of the total surface area of agricultural land. The accumulation of P in soils shows up in the soil fertility evaluation results of for example BLGG. Approximately 30 to 60% of the agricultural land has a high P status, 20 to 40% has the status sufficient to moderately high, 10 to 30% has status sufficient and 0-10% has the status low (RIVM, 2002). About 80% of the agricultural land on sandy soil is so-called P-saturated and about 30% is strongly saturated.

Currently, soils of the Netherlands are among the richest in the world, in terms of P accumulation. High levels of P accumulation in soils are associated with areas with high density of livestock, where the animal production relies on important animal feed. Such areas are found scattered over the world, especially in The Netherlands, parts of Belgium and the USA. In general however, all soils in the developed (OECD) countries have P enriched soils through the use of P fertilizer. In many of these countries, mean P fertilizer use is higher than the mean P fertilizer in the Netherlands. In the Netherlands, P fertilizer use per unit of ha started to decrease from the 1950s onwards, in response to the increasing availability of animal manure and the increasing soil P status, while the P fertilizer consumption in the other OECD countries started to slow down much later (from the 1980s).

P saturated soils

On P saturated soils, the risk of leaching too high amounts of P to surface waters and groundwater is increased. Especially wet soils have low P retention capacity and high P saturation index. Figure 6 shows the distribution of P saturated soils in the

Netherlands. Basically, these soils are found throughout the country, but especially in areas with shallow groundwater level (wet soils). The proximity of surface waters makes these P saturated soils a large environmental burden. In P saturated soils come two unique features of soils in the Netherlands together, namely their intensive use (and manuring and fertilization history) and the wetness, the shallow groundwater level. This is rather unique for the EU-15 and elsewhere. Rather similar places can be found locally in Belgium, the Po area in Italy and Delaware, along the eastern coast of the U.S.

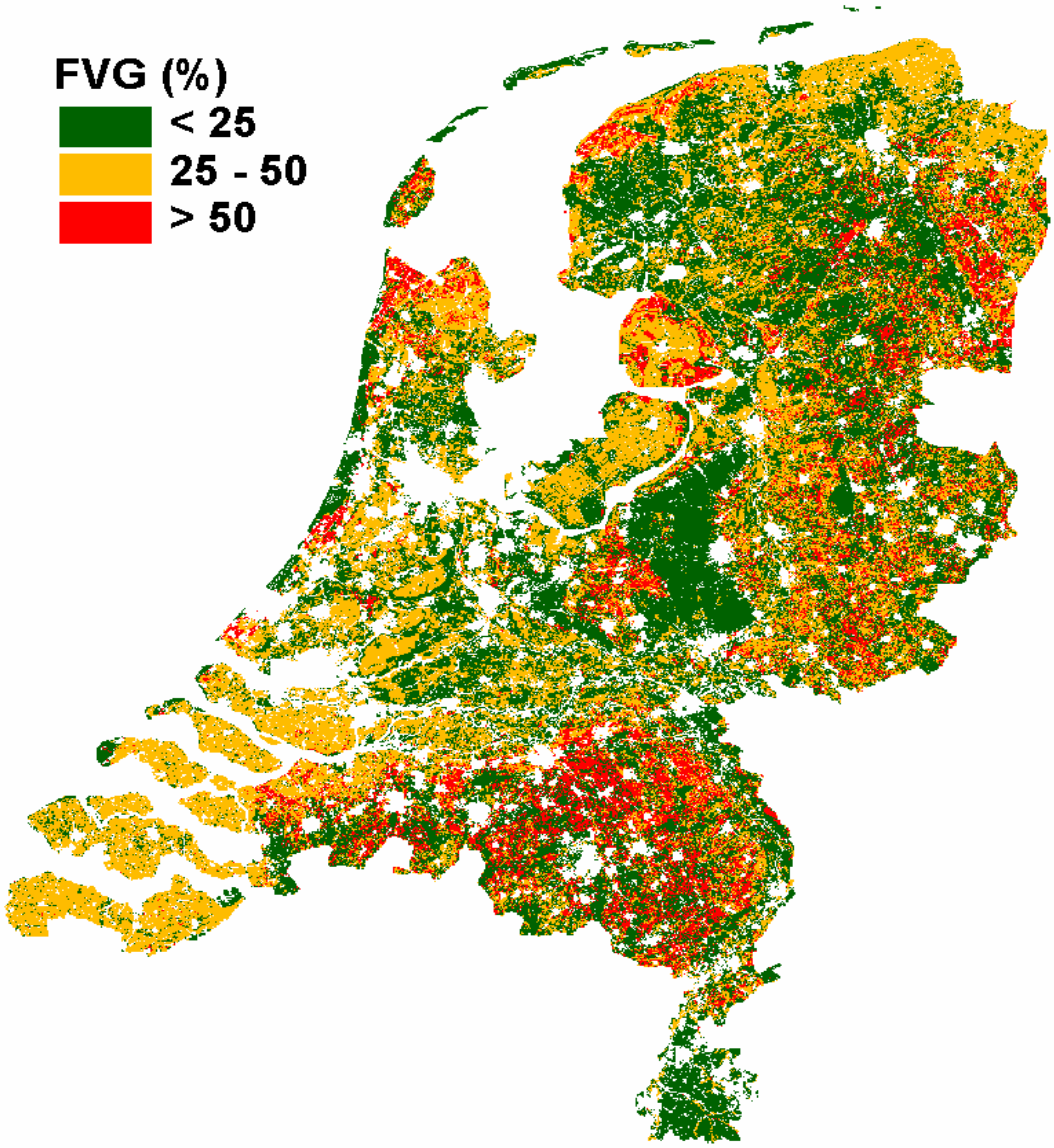

Figure 6. Spatial pattern of calculated phosphorus saturation index (FVG). Soils with a FVG of more than 25% are termed phosphorus saturated soils, meaning that the P leaching losses to groundwater and surface waters exceed or will exceed environmental quality standards for these waters. Soils with a FVG of more than 25% are termed phosphorus saturated soils are termed strongly saturated soils, meaning that P leaching losses are far too high to satisfy environmental quality standards.

Despite nearly 20 years of manure policy, the accumulation of P in agricultural soils still continues, though the rate of accumulation has diminished greatly over the last five years. The accumulation rate has diminished from an average of 30 to 40 kg of P in the years between 1950 to 2000, to an average of about 10 to 20 kg P per ha per year in 2003. The high P saturation index of many soils in the proximity of surface waters and the ongoing P accumulation without a clear perspective on reversal is an environmental, social and political drama. The consequences of this drama will become clear to some extent when the demands of the EU Water Framework Directive become clearer. So far, the Water Framework Directive is the most substantial piece of EU water legislation. It requires all inland and coastal waters to reach good ecological status by 2015. It will do this by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters. It addresses all compounds that affect the ecological status of surface waters, including N and P from agriculture.

There is as yet not much experience with the ecological safe management of P saturated soils. Soils with a high P status tend to obstruct nature development projects for many years, unless the P-rich top layer is removed and replaced by soil with a low P status. P-saturated soils near surface waters will continue to leach relatively large amounts of P into these surface waters for many years, thereby obstructing surface water quality for many years. Experiments under controlled conditions suggests that the removal of soil P through harvesting unfertilized crops is an effective way of decreasing the leaching of dissolved P (Koopmans, 2004), but these experiments have to be confirmed by field experiments.

Manure policy

Nowadays, there is abundant information about N and P balances of all types of farms in the Netherlands, and about N and P in groundwater and surface waters. This information has become available in response to the implementation of the so-called manure policy from the second half of the 1980s onwards, and in response to the need to monitor the effectiveness of these policy. The manure policy addresses the use of N and P from animal manure and fertilizers, in part in response to the EU-Nitrate Directive. Basically, the manure policy in the Netherlands is a nutrient policy, or a N and P policy for agriculture. An overview of the changes in these policies and of the results of the two recent fact-finding studies about the manure policy can be found in RIVM (2002; 2004) and references therein. These reports clearly summarize the huge complexity of both the manure problem and current manure policy.

There is a growing understanding that the problems associated with the excess amounts of N and P in animal manure and fertilizers are related to the structure of agriculture. Implementation of a 'simple' manure policy and EU Nitrate Directive can not solve the nutrient problem at short notice, because it is too complex. There are huge economic, ecological and social consequences. The human dimension has been overlooked or underestimated. The farmers community is a diverse community that need time to learn and to change.

There is a growing believe that the manure problem can only be 'solved' in a transition of current agriculture to a sustainable agriculture (VROM, 2001). Such a transition will take about one generation, and will require a huge effort of all stake-holders involved, including farmers, suppliers, processing industry, retailers and consumers.

Conclusions

- Most soils of agricultural land in the Netherlands have a high native soil fertility.
- In the second half of the 20th, agricultural soils have been enriched by on average 2000 kg P per ha. Some soils have accumulated double or triple this amount
- The surplus amount of N in the second half of the 20th century was on average 20,000 kg N per ha. Almost all of this surplus has been lost and is dissipated into the wider environment.
- The annual surpluses of N and P have decreased drastically during the last decade, but there is an ongoing enrichment of P in essentially all soils.
- Effects of excess N are immediate at local scale, and become apparent slowly at regional and continental scale through diffusion (via groundwater and surface waters, and via the atmosphere as NH_3 and N_2O).
- Effects of excess P are masked in part through buffering by the soil. Effects may become apparent after the continued application of excess P has consumed (vanished) the buffering capacity of the soil. The increased leaching of P will last many decades and the ecological effects may slowly become apparent at regional scale through diffusion.
- Phosphate saturated soils can be considered as an environmental mortgage, which is still growing in size and area and which sooner or later has to be redeemed. It should be noted that this mortgage also withdraws P from the market that can be utilized more effective elsewhere.

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4.3 Pesticides

A. Tiktak (RIVM)

The term 'pesticides' is a generic name, which encompasses all substances or products that are used to control pests, whether used in agriculture or for other purposes. Pesticides can be subdivided into two main categories, i.e. biocides and Plant Protection Products (PPPs). Biocides are used to exert a controlling effect on unwanted or harmful organisms in non-agricultural sectors, e.g. for wood preservation or disinfecting purposes. PPPs are used to protect plants or plant products; they are used in a wide range of applications, such as agriculture, landscape gardening and along transport routes. Contrary to biocides, PPPs are applied across large areas of land and form a major source of diffuse pollution, so this chapter will focus on PPPs only.

Environmental threats

PPPs are probably the only hazardous[2] chemicals that are deliberately brought into the environment during application. PPPs are primarily used in the agricultural sector (see below) and enter the soil after spraying, injection or incorporation. If not used in substrate cultivation in glasshouses, it is inevitable that PPPs reach the soil. Outside agricultural areas soils may become contaminated due to drift or atmospheric deposition. The concentration in the soil and the toxicity of the PPP to soil organisms determine its impact on the soil ecosystem. Immediately after application PPPs may cause acute toxic effects on soil organisms other than soil-borne pests and diseases, for example on earthworms and beneficial arthropodes. This is undesirable, also from an agricultural point of view, because agriculture benefits from the presence of these organisms. Spray drift, leaching to the groundwater, drainage to local surface waters and run-off are diffuse sources of uncontrolled dispersion of PPPs into other environmental compartments. Notice that leaching to the groundwater and drainage into surface waters is soil mediated.

Not only environmental quality is affected by the use of PPPs, also the agricultural sector itself is affected. Control of pests and diseases may be hampered by the development of resistance against PPPs.

Reliance of the agricultural sector on PPPs became painfully clear after the withdrawal of some key PPPs from the market. Dutch agricultural is particularly sensitive to this problem, because there are a large number of so-called minor uses (i.e. uses in crops that are grown on small areas of land such as onions). In these cases, producers of PPPs may not find it financially worthwhile to go through the complicated re-evaluation procedures as required by the European PPP Directive (see below).

[2] Most PPPs are hazardous substances. About 500 PPPs are included in annex 1 of Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances.

PPP use in the European Union

Agriculture is by far the biggest PPP using sector in the European Union. Non agricultural use (such as in private gardens) is estimated to account for only 2% of total PPP use. The EU currently accounts with approximately 320,000 tons of active ingredients sold per year for one quarter of the world market of PPPs. The major types of PPPs are fungicides (43% of the market), followed by herbicides (36%), insecticides (12%) and other PPPs (9%). The use of PPPs varies depending on the type of agricultural produces. The largest quantities of PPPs, expressed in kg/ha, are used in viniculture, fruit and vegetables, floriculture, flower bulbs, potatoes and sugar beet. The application of PPPs per hectare of arable land varies widely between European countries. The Benelux countries have the highest use of PPPs per hectare followed by the United Kingdom, France and Portugal. The Nordic countries have the lowest PPP use per hectare in the EU-15 (Figure 7). Herbicides are predominant in the Northern and Central European countries, whereas insecticides and fungicides dominate in the Southern and Western countries.

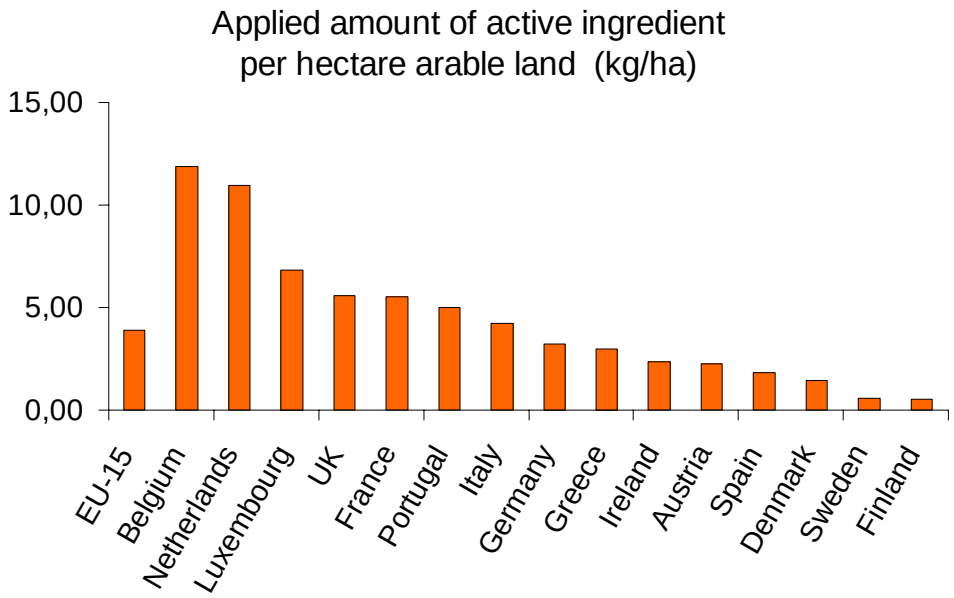

Figure 7. Intensity of PPP use by Member State in 1998 (from Snoo and de Jong, 1999).

Pesticide authorization – prevention at source

Because of the particular circumstances of PPP use – deliberate release of potentially hazardous substances into the environment – they have been regulated for a long time in most Member States and at the European Level. Most of the legislation has focussed on the authorization of substances for use in PPPs before they are placed on the market (hence in the spirit of prevention at source). The key legal instrument at the European level is Council Directive 91/414/EEC concerning the placing on the market of PPPs. The main objective of this directive is to guarantee that individual PPPs have no harmful effects on human and animal health and no unacceptable effects on the environment. The Directive provides a two-step process: active substances for which the evaluation has shown that there are uses which pose

no such unacceptable risks are included in Annex 1 to the Directive. Only substances that occur on Annex 1 can be submitted for registration in individual Member States. In the Netherlands, registration procedures are laid down in the Dutch Pesticides Act of 1962 and amendments. In 1995, the Netherlands issued the so-called environmental criteria as an amendment to the Pesticides Act (Anonymous, 1995), specifically with respect to persistence in the soil, leaching to the groundwater and risks to aquatic organisms in surface water. Directive 91/414/EEC also initiated a 12-years program to review all active substances that were already on the market. The strategy was to substitute PPPs with adverse effects on the environment for substances that were less detrimental. In response to this strategy, the number of substances on the Dutch market decreased from 1620 in 1985 to 675 in 1999 (Snoo and de Jong, 1999).

Monitoring

Persistent PPPs are substances that are very slowly degraded in the environment. As persistence is now an criterion in the authorization procedure (PPPs cannot be registered without additional fact-finding studies, if the half-life is above 90 days in EU-15 and 180 days in The Netherlands), modern PPPs will not accumulate in soils. However, there is still discussion about the criterion of persistence in the registration and authorization procedure of PPPs.

Old PPPs can still be found back at potentially hazardous levels in many Dutch soils (Table 2). It is expected that the concentrations of these persistent substances will decrease very slowly.

Table 2 Occurrence of PPPs in soils (Source: Groot et al., 1998)

Substance	β-HCH	γ-HCH	HCB	β-HCE[2]	Aldrin	Endrin	Dieldrin	α-ESF[2]	DDTs
Withdrawn in:	1999	1999	1973	1978	1982	1988	1980	1990	1973
Threshold value[3] (µg/kg)	9	0.05	2.5	0.0002	0.06	0.04	0.5	0.01	10
Samples above the threshold value (%)[1]	0-66	20-100	0-100	0-90	0-36	0-28	6-100	0-30	5-70

1) Original report distinguishes between land-use categories. This table only shows the values for the category with the smallest number of samples above the threshold value and the category with the largest number of samples above the threshold value.
2) HCE = heptachloro-epoxide; ESF = endosulphan
3) Negligible Risk Level; in Dutch 'streefwaarde'

PPPs are also detected at levels above threshold values in Dutch surface waters (CIW, 2000) and in the groundwater (Nooteboom *et al.*, 1999). With respect to surface water, 10 substances that currently have a registration were detected on a regular base. Four of these substances (MCPA, mecoprop-p, carbendazim and bentazone) were detected very frequently. In groundwater, a total number of six currently registered substances were frequently detected in the shallow groundwater (Nooteboom *et al.*, 1999). Also substances that are no longer on the market such as the broad-spectrum herbicide atrazine can still be found in surface waters and in the groundwater. Moreover, 12 out of 19 drinking water production companies had to make additional costs due to the presence of PPPs (Kiwa, 2001).

Vulnerability of Dutch soils to PPP leaching and drainage

Not all soils are equally vulnerable to leaching and drainage. Figure 3 shows the spatial pattern of the vulnerability of Dutch soils to leaching and drainage. Vulnerability is assessed by performing simulations with a spatially distributed PPP leaching model (Tiktak *et al.*, 2002). Figure 3 shows that the vulnerability of soils to drainage is generally higher in the western and northern part of the country. This part of the country is characterized by shallow groundwater levels and a high density of the drainage network. Additional analyses showed that discharge by rapid drainage mechanisms (i.e. tube drainage and surface drainage) dominated. This finding is important, because PPPs discharged through such rapid drainage mechanisms reach the surface water with relatively few interactions with the soil matrix. Figure 8 also shows that the leaching problem is high in the eastern and southern parts of the country. This area is characterized by well drained, slightly acidic sandy soils. Vulnerability to leaching is further high in soils with a low organic matter content, such as loess and dune soils.

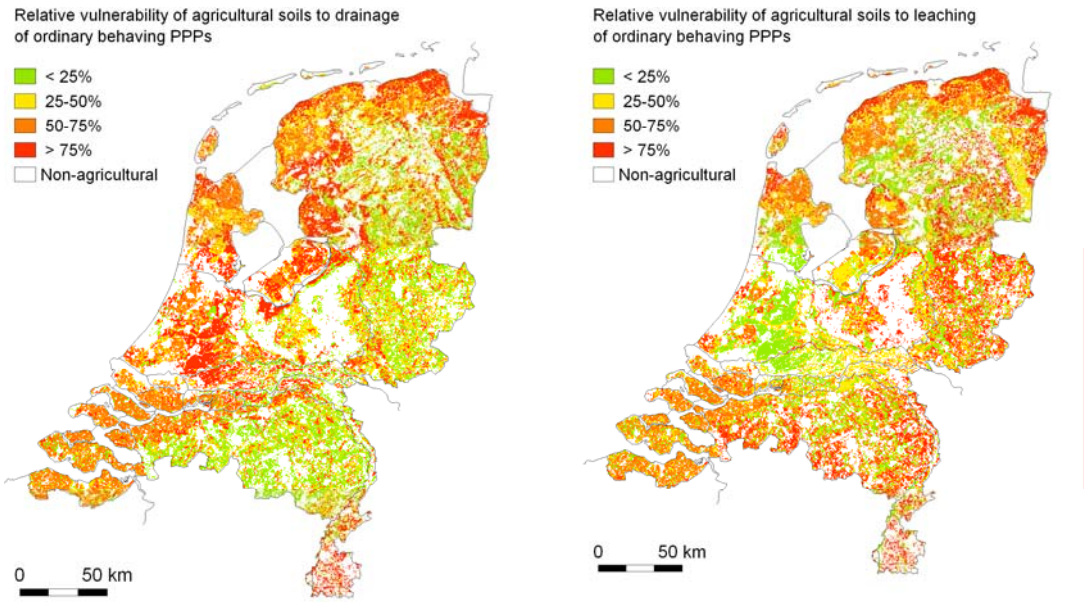

Figure 8. Comparison of the spatial pattern of the relative vulnerability of Dutch soils to drainage (left) and leaching (right) of an example PPP (after Tiktak et al., 2002). Figures denote the class in the accumulated frequency distribution, for example 50% means that half of the soils are more vulnerable .

The Multi-Year Crop Protection Plan

To minimize adverse effects of the use of PPPs on environment and the agricultural sector, the Dutch Government launched the *Multi-Year Crop Protection Plan*, MJP-G (LNV, 1991). Strategic objectives were: (i) reduction of the dependency of the agricultural sector on PPPs, (ii) reduction of the use of PPPs, expressed in quantities of active ingredients, and (iii) reduction of the emission of PPPs to groundwater, surface water, non-agricultural soil and the air. These objectives had to be achieved through various measures, such as integrated pest control, crop rotation and introduction of crop varieties that are less susceptible to pests and diseases. One of the targets was to reduce PPP use by 50% by the year 2000. Figure 9 shows that this

targets was met by 1993. This reduction was achieved primarily through the reduction of the use of soil fumigants; the use of other PPPs, particularly fungicides and herbicides, stayed at a constant level. It was shown that other policy instruments, like cross-compliance, only accounted for 5% of the total reduction of PPP use.

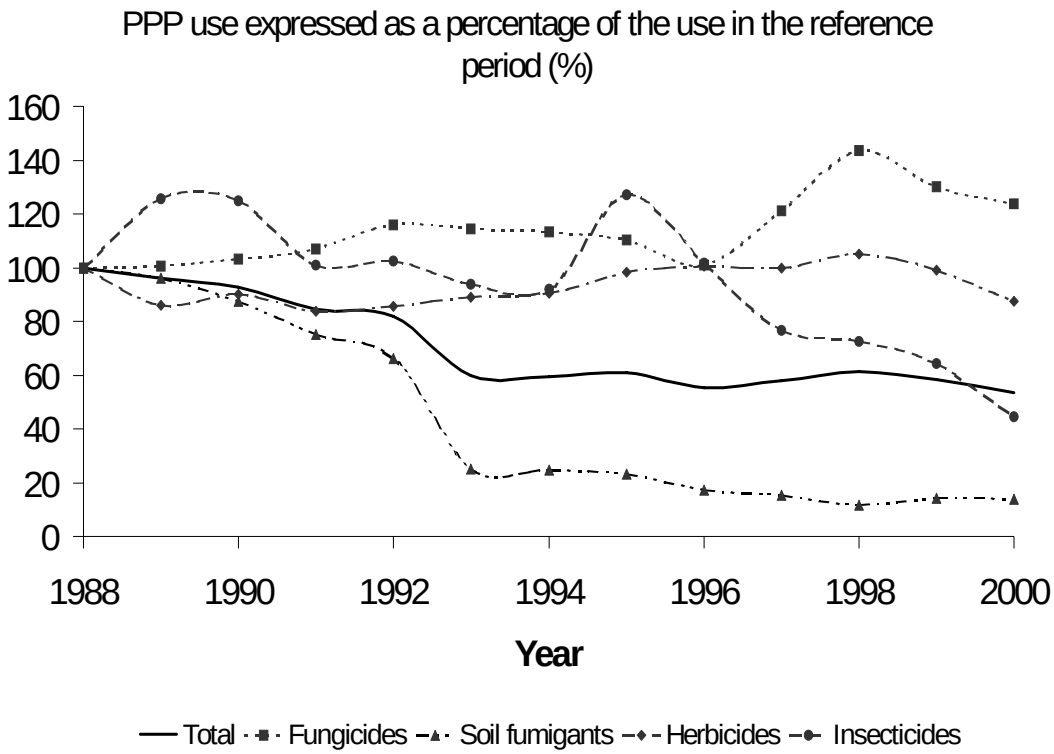

Figure 9. PPP use of different types of PPPs, expressed as a percentage of the use in the reference period (1984-1988). Source: EC-LNV, 2001.

The other objective of the MJP-G, reduction of the emission to the environment was met for air, soil and groundwater, but not for surface water (Table 3). Despite the fact that the reduction percentages were (almost) met, both model calculations (Tiktak *et al.*, 2002) and measurements (see above) showed that concentrations in groundwater and surface water were still exceeding threshold values.

Table 3 Planned and realized reduction of emission to environmental compartments in 1995 and 2000, expressed as a percentage of the emission in the reference period (1984-1988).

Compartment	Reduction in 1995		Reduction in 2000	
	Realized	MJP-G target	Realized	MJP-G target
Soil[1]- and groundwater	69%	40-45%	79%	≥ 75%
Air	46%	30-35%	54%	≥ 50%
Surface water	59%	> 70%	79%	≥ 90%

[1)] Non-agricultural soils affected by spray-drift and atmospheric deposition.

Sustainable Crop Protection Plan

After the evaluation of the Multi-Year Crop Protection Plan, it became clear that additional policy instruments were required to further reduce environmental pressure by PPPs. For this reason, the Dutch government launched the policy plan *'Sustainable Crop Protection'*. This plan aims, amongst others, at reducing the concentration in all

environmental compartments to the targets set in the Fourth National Environmental Programme (NMP4), i.e. Maximum Tolerable Risk (MTR) values by 2010 and Negligible Risk (VR) values by 2030. Accomplishment with the MTR values comes down to an ambitious reduction of the environmental pressure by 95% during the period 1998-2010. Notice that reduction percentages are effects based instead of volume based as was the case in the MJP-G. The plan suggest the following four instruments to reach the targets:

- Stimulation of integrated crop protection. Elements of integrated crop protection are a crop protection plan, measures to avoid the import of pests and diseases at the farm level (for example by disinfection of equipment and the use of certified seed) and minimum-use techniques;
- Stimulation of technical innovations that make minimal-use techniques possible;
- Mandatory training and education programs for PPP applicators and users. The training should put emphasis on safe use, covering both human health and environmental health;
- Technical checks and certification of application equipment;
- A mid-term evaluation of the policy plan is foreseen in 2006.

European Policy Instruments

European policy instruments set boundary conditions for Dutch PPP policy. The most important instruments that are currently in force, other than Directive 91/414/EEC are listed below:

- The 6th Environmental Action Programme (6EAP). As part of this programme, the commission published a communication on a thematic strategy on the sustainable use of pesticides (COM 2002:349 final). This proposed strategy has much in common with the Dutch Sustainable Crop Protection Plan mentioned above.
- The Water Frame Directive (Directive 2000/60/EEC), which marks a change in water policy towards a coherent and integrated framework for assessment, monitoring and management of all surface waters and groundwater based on their ecological and chemical status. For the protection of surface waters, the Directive introduces a list of 33 priority substances; 13 of these are PPPs. Member states must propose measures to minimize emissions of these substances into the surface water. With respect to groundwater, a daughter directive is currently under development. With regards to active ingredients in PPPs, the present limit value (0.1 $\mu g\ L^{-1}$) in registration is also considered the Maximum Tolerable Concentration for defining good groundwater status.
- Common Agricultural Practice (CAP). The latest reform of the CAP, as established in the Agenda 2000, is designed on integrating environmental requirements into the CAP. This has been pursued by cuts in market support and a strengthening of rural development policy. Regulation 1259/1999 establishes a link between environmental protection requirements and direct support to farmers from the CAP. Regulation 1257/1999 calls for the development of integrated programs at regional level for the sustainable development of rural areas. Relevant for PPP use are the agri-environmental measures, through which farmers are paid for services they provide beyond the level of normal Good Farming Practice (the so-called green services).

Conclusions

Dutch agriculture is intensive and uses the largest amount of PPPs per hectare of arable land in Europe, together with Belgium. PPP use is regulated by strict authorization procedures, which are harmonized with European procedures. Environmental criteria include persistence in the soil, leaching to the groundwater and risks to aquatic organisms in surface waters. Persistent substances are successfully banned from the Dutch market, but old PPPs are still found back in Dutch soils across large areas of land. On the contrary, some PPPs that currently have a registration are frequently detected in surface waters and in the groundwater. Policy plans to reduce the environmental pressure by PPPs have been in force already since the beginning of the nineties. These policy plans were successful in reducing the use of certain groups of PPPs, but other problems like reliance of agriculture on PPPs and environmental pressure are persistent. European policy instruments like the Water Frame Directive and the Common Agricultural Policy will set boundary conditions for Dutch policy. The protection of soils – other than prevention of accumulation - is not a specific target of current PPP legislation; most legislation has end-points in the groundwater or in the surface water. This implies that PPPs may still cause acute and chronic toxic effects on soil organisms other then soil-borne pests and diseases, even if the targets of other legislation have been met. As these organisms are important to the functioning of soils, specific PPP legislation should be incorporated in the proposed thematic soil strategy to guarantee the functioning of soils, now and in the future.

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4.4 Atmospheric N and S depositions

W. de Vries

Atmospheric depositions of nitrogen (N) and sulfur (S) compounds contribute to soil acidification and to eutrophication of natural ecosystems. Soil acidification is defined as a decrease in soil acid neutralizing capacity, which is associated with a decrease in pH and base cations in the soil. Eutrophication is defined as the enriched of natural ecosystems with nutrients like N and P, which lead to a boost in primary production, a strong decrease in species diversity and nature value (ecosystem simplification), and various other negative side-effects, especially in aquatic ecosystems.

Soil acidification through acidic atmospheric depositions was a major policy issue between 1985 and 1995. The major reason for this was the assumed threat for large-scale forest decline, based on the hypothesis of the German professor Ulrich that atmospheric depositions of acidifying compounds cause soil acidification, which in turn will lead to elevated concentrations of toxic aluminum (Al) in the soil and than to forest dieback. Though elevated Al concentrations in acidic forest soils have been observed, and elevated Al concentrations do have adverse effect on root morphology and functioning, the assumed dramatic forest dieback did not occur.

Soil acidification is a natural process. This process is accelerated by leaching, atmospheric deposition of acidifying compounds (from industry, traffic and volcanoes), and through agricultural activities. Agricultural activities that contribute to soil acidification are the application of (acidifying) N fertilizers, harvest of crops containing excess cations, land use changes and drainage. In agriculture, acidic soils are regularly amended through the application of lime ($CaCO_3$) and other acid neutralizing soil amendments (compost, manure, earth foam). As a result, soil acidification is not a big issue in agriculture. The reverse is true for soils of forests and natural grasslands, and for lakes, ponds, streams and fens, as application of acid neutralizing compounds has various unwanted side-effects here, and is therefore no an accepted practice. Mitigation and combating soil acidification in forests and natural grasslands can only be achieved through decreasing the sources of acidification, i.e. atmospheric deposition of acidifying N and S compounds, as this is the major source of soil acidification in forests and natural grasslands.

Trends in emissions and atmospheric depositions of S and N compounds

Trends in national emissions of S and N compounds in the period 1950-2000 and the national emission target for 2010 are presented in Table 4. The data show a strong decrease in the emission of sulfur oxides. Between 1970 and 2000 the decrease in emission of sulfur oxides was approximately 90%. Emission of sulfur oxides peaked in 1965 at a level of 1010 kton.yr^{-1} (1 kton = 1 Gg). Emission of nitrogen oxides and ammonia peaked between 1980 and 1990. For the nitrogen oxides and ammonia, the decrease in emissions compared to the peak levels in the middle of the 1980s is approximately 30%. Despite the reduction in S and N emissions, soil acidification and specifically eutrophication remains a threat to soils and natural ecosystems.

Table 4. Trends in emissions of sulfur oxides (SO_x), nitrogen oxides(NO_x) and ammonia(NH_3) between 1950 en 2000 and the national emission target for 2010 (NMP4) in kton.yr^{-1}. (Source: Thomas et al., 1988 for data to 1980; Van Wee et al., 2001 for data since 1980). Note: 1 kton = 1 Gg.

Year	Sulfur oxides	Nitrogen oxides	Ammonia
1950	510	175	105
1960	814	250	130
1970	810	410	180
1980	481	585	234
1990	202	574	231
1995	141	484	191
2000	91	421	157
2010 (target)	46	231	100

Partly in response to these changes in atmospheric depositions over the past decades and specifically since 1995, policy interest shifted from effects of S-deposition and soil acidification towards effects of N-deposition and eutrophication. Eutrophication is defined here as the accumulation of N in the soil that lead to changes in the ecosystem, i.e. a decrease in species diversity. There are three main reasons for this change in interest:

(i) the emissions of SO_2 and thereby the atmospheric concentrations and depositions of SO_4 dramatically decreased over this period, both in the Netherlands and in most parts of Europe,

(ii) the expected large-scale forest dieback as a result of soil acidification did not occur, and

(iii) the effects of N deposition and associated effects of eutrophication appeared to be much dramatic and widespread than the effects of S deposition.

Both in the Netherlands and in Europe, atmospheric N deposition is considered as extremely important for both soil acidification and biodiversity of natural areas. The species richness of natural vegetations can change dramatically in response to eutrophication by atmospheric deposition.

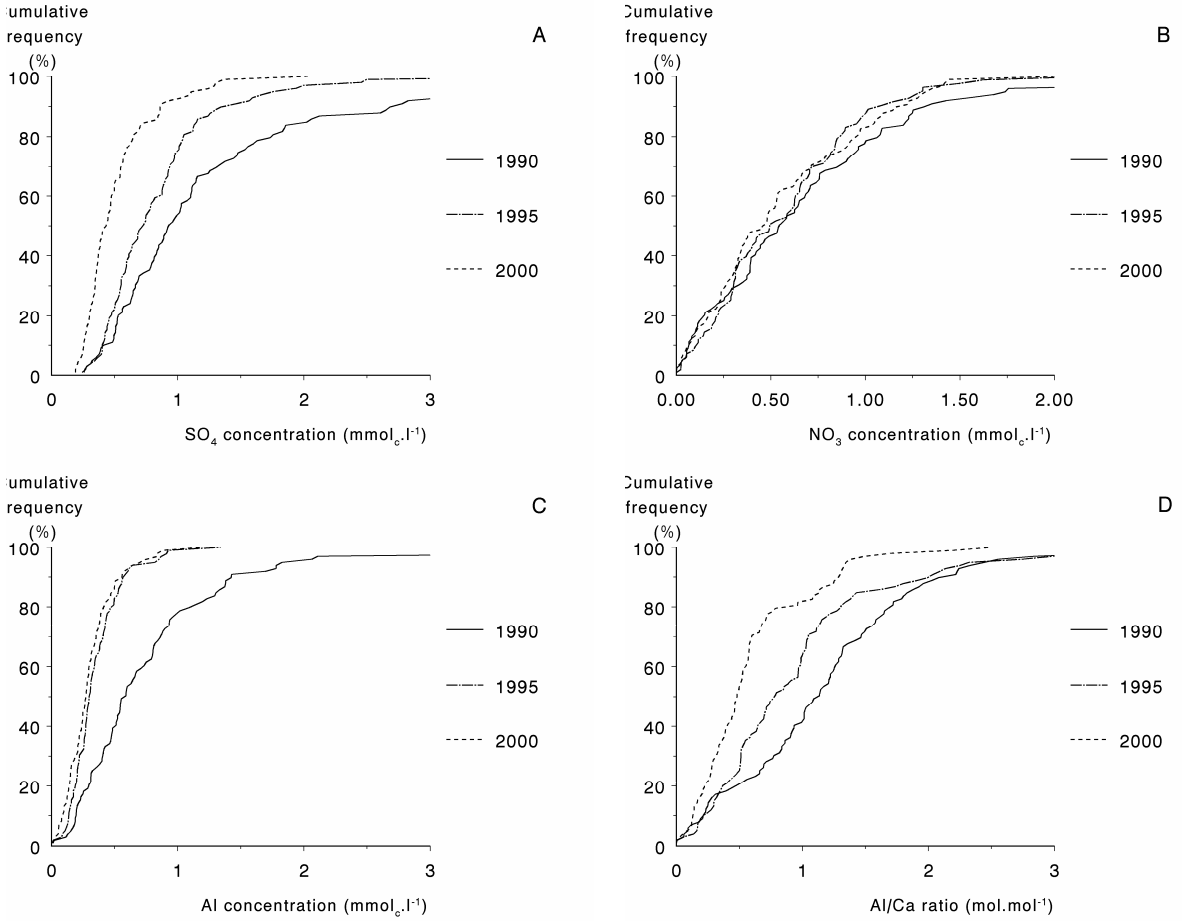

Figure 10. Frequency distributions of the dissolved concentrations of SO_4, NO_3 en Al and the ratio of Al to Ca in 124 non-calcareous forest soils in the Netherlands for the years 1990, 1995 and 2000.

Effects of atmospheric N and S depositions on soil solution chemistry

Atmospheric depositions of S and N compounds contribute to a decrease in soil base saturation and soil pH. The acidity generated by atmospheric depositions of S and N compounds in acidic soils, such as most forested soils in the Netherlands, is mainly neutralized by the dissolution of aluminum (Al). In these soils, atmospheric depositions of S and N compounds lead to elevated concentrations of dissolved Al in the soil solution concomitant with an increase in dissolved concentrations of sulfate (SO_4) and nitrate (NO_3). These conclusions could be derived from results of input-output budgets of major ions in 150 forest stands on non-calcareous sandy forest soils in the Netherlands (De Vries et al., 1995).

Decreases in S and to a lesser extent N depositions during the last few decades caused a considerable change in soil solution chemistry. These changes are illustrated in Figure 10. This figure presents the cumulative frequency distributions of dissolved concentrations of SO_4, NO_3 en Al in 124 non-calcareous forest soils in the Netherlands for the years 1990, 1995 and 2000 The results do illustrate the much larger decrease in dissolved SO_4 concentration compared to the NO_3 concentration.

Concentrations of Al also decreased strongly and as a consequence, Al/Ca ratio too (De Vries et al., 2002).

Effects of atmospheric N depositions on N leaching

At high levels of atmospheric N deposition, all N can not be taken up by the vegetation and leaching may occur. Results of N leaching against total N deposition show that the leaching of N is generally negligible below a total N input of 10 $kg.ha^{-1}.yr^{-1}$. This is illustrated in Figure 11, presenting a scatter plots of N leaching against N deposition at more than 100 intensively monitored forest plots in Europe (De Vries et al., 2001). At N loads above 20 $kg.ha^{-1}.yr^{-1}$, the N leaching is generally increased but the results are highly variable. N deposition in the Netherlands is near 40 $kg.ha^{-1}.yr^{-1}$.

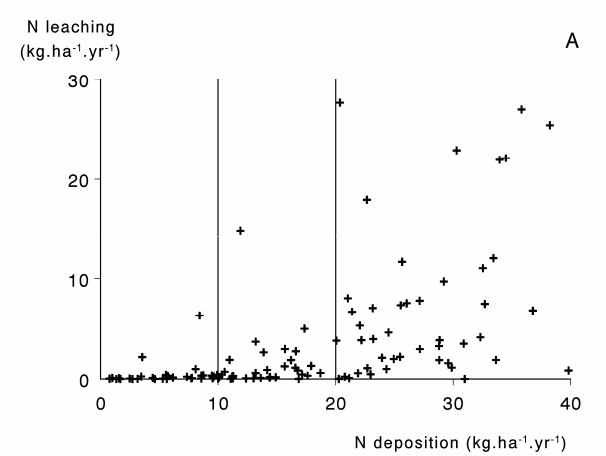

Figure 11. Scatter plot of N leaching against N deposition at more than 100 intensive monitoring plots.

Complete N saturation of forested soils (defined as a situation where N outputs via leaching equals N inputs via atmospheric deposition) depends on the (dis)equilibrium between N input to the humus layer by litterfall and the N output from this layer by mineralization. Immobilization of N in organic matter causes retention of N in the soil. This appears still the case in many humus layers of forests in the Netherlands. Even at the high N inputs encountered in the Netherlands, complete N saturation may thus still await some time. However, it is clear that the forest area approaching N saturation will strongly increase in the coming decades, unless N inputs are decreased.

Ecological effects of increased N and S depositions

Apart from the effects on soil solution chemistry, increased inputs of N and S compounds to natural ecosystems lead to:

(i) a loss of species diversity, sometimes accompanied by a strong dominance of one or a few acid-resistant species in moorland pools on sandy soils (Roelofs et al., 1996),

(ii) a decline of the diversity of grasslands on poor, sandy soil (De Graaf et al., 1997) and

(iii) a decrease in epiphytic lichens (Van Herk, 2001).

However, in most cases also other factors contribute to the reported decrease in species diversity. The decrease in biodiversity of moorland pools may be partly ascribed to desiccation and to eutrophication (Lamers et al., 1998 a, b). The decline of the number of species in grasslands is probably caused by a combination of acidification and eutrophication, where toxicity of Al ions and a shift in the NH_4/ NO_3 ratio are the triggers (De Graaf et al., 1998). The decline in epiphytic lichens is mainly due to direct toxicity of SO_2, but also due to acidification, eutrophication and toxicity of NO_x (e.g. Van Herk 2001). The decline in epiphytic lichens is probably best described as an air-pollution induced ecological effect over time (e.g. Van Herk et al., 2002). The dramatic changes that took place in the epiphytic lichen flora of north-western Europe during the past two decades can be ascribed to a combination of decreasing SO_2 concentration, increasing NH_3 concentration and climate change (Van Herk et al., 2002).

Nitrogen saturation is accompanied by increased levels of nitrogen in plant foliage, which in turn may increase susceptibility of plants to frost, drought and diseases. This effect is well-documented for forest trees, but also occurs in e.g. Calluna vulgaris (Achermann & Bobbink, 2003). In this context, a critical N content of 1.8% in needles has often been mentioned in the literature, which translated to a critical N load near 20 $kg.ha^{-1}.yr^{-1}$ (De Vries et al., 2003).

A possible consequence of high N contents in foliage is a nutritional imbalance, i.e. deficiencies of the macro nutrients K, P, Mg and Ca relative to N in needles. Van den Burg and Kiewit (1988) showed that the N content in needles strongly increased between 1956 and 1988 (Table 5), the period in which both the emission of NH_3 and NO_x increased strongly (see Table 4). The nutrient ratios of K and Mg compared with N decreased significantly during this period. No systematic inventories have been carried out yet during the period 1988 to present.

Table 5. Average N content and ratios between K, Mg and N concentrations in half-year-old needles in 1956 and 1988 (Van den Burg and Kiewit, 1988).

Tree species	N content (% dry weight)		Nutrient ratio x 100 ($g\ g^{-1}$)			
			K/N		Mg/N	
	1956	1988	1956	1988	1956	1988
Scots pine	1.5	2.3	34	27	3.0	2.7
Corsican pine	1.2	1.7	58	35	4.0	3.8
Douglas fir	1.4	2.2	68	24	6.1	5.0

Results on ranges in atmospheric N deposition at plots with a balanced and unbalanced ratio of the base cations K, Ca or Mg to N at approximately 100 Intensively Monitored plots in Europe clearly indicated a larger N deposition at the plots with an unbalanced ratio. The median N deposition was 10 $kg.ha^{-1}.yr^{-1}$ at plots with a balanced nutrition and 21 $kg.ha^{-1}.yr^{-1}$ at plots with an unbalanced nutrition. This translates to a critical load of approximately 10-15 $kg.ha^{-1}.yr^{-1}$ in view of tree nutrition (De Vries et al., 2003).

Effects of atmospheric N deposition on biodiversity are now recognised in nearly all oligotriophic natural ecosystems including aquatic habitats, forests, grasslands

(including tundra, montane and Mediterranean grasslands), oligotrophic wetlands (mire, bog and fen), heathland, and coastal and marine habitats (Achermann & Bobbink, 2003). In such oligotrophic systems, nitrogen is generally the most important growth-limiting element, and their species are adapted to a nitrogen-deficient environment. If the availability of nitrogen increases, other species that use the available nitrogen more efficiently will outcompete the unproductive species adapted to nitrogen deficiency. An effect that should also be mentioned here is the loss of diversity in wetlands due to acidification and the resulting increase in mineralisation at high sulfate concentrations ('internal eutrophication') (Lamers et al., 1998a,b). In the Netherlands, critical loads related to impacts on biodiversity generally range between 10-35 $kg.ha^{-1}.yr^{-1}$ with an average value near 20 $kg.ha^{-1}.yr^{-1}$ (Van Dobben et al., 2004).

Establishing critical loads for atmospheric depositions

Already in 1979 the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission of Europe (UNECE-CLRTAP) was established. It addresses air pollution in Europe and northern America. Under the Convention, in which the Netherlands does participate, regional scale trend assessments and risk evaluations have been carried out. Risk assessments mostly focused on the difference between present deposition of S and N compounds and the critical deposition or critical load. The definition of critical load that is now generally accepted is that it is 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'. In this context, 'significant harmful effects' may be (a) chemical changes in soils and waters which might cause direct or indirect effects on organisms, or (b) changes in individual organisms, populations or ecosystems (Nilsson & Grennfelt, 1988).

The ICP-Modelling and Mapping under the UNECE-CLRTAP has developed maps of critical loads for European (predominantly forest) soils below which deposition of acidifying or eutrophying compounds do not lead to damage according to current scientific knowledge. This ICP is supported by a co-ordination center on effects at RIVM, the Netherlands and the methods used to derive critical loads were largely derived in the Netherlands and Sweden (e.g., De Vries, 1991; Sverdrup and de Vries, 1994). These maps were and are used to support protocols for the reduction of acidification and eutrophication (Hettelingh et al., 2001).

In the middle of the 1980's, the first assessment was made of average critical loads for various ecosystems in The Netherlands. Calculations made at that time showed that critical acid loads aiming to prevent adverse effects on forest soils are in the range of 1100-1700 $mol_c\ ha^{-1}\ yr^{-1}$. Critical acid loads for sensitive shallow groundwater and surface waters are in the range of 300-500 $mol_c\ ha^{-1}\ yr^{-1}$, which are much lower than the critical N loads aiming to prevent NO_3 pollution in shallow ground water (1500-3600 $mol_c\ ha^{-1}\ yr^{-1}$). Critical N loads are low (500-1400 $mol_c\ ha^{-1}\ yr^{-1}$) when the criterion is to prevent changes of the vegetation in forests, heathlands and surface waters (De Vries, 1993).

It is difficult to derive a critical load for forests because forest vitality is also influenced by natural stress factors, such as drought, frost and diseases. Development of multi-stress models in which such effects are included is therefore very important. Considering the various stresses on forests and the possibility of adaptation, one has to be aware that critical loads for forests mainly have a signal function. When atmospheric inputs exceed critical loads, it does not necessarily cause visible effects and dieback of forests. However, an exceedance of critical loads does affect the long-term sustainability of forests. This risk increases when the exceeding of critical loads is large and lasting.

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5 Soil Erosion

J. Stolte

Soil erosion is defined as the physical removal (transportation) of soil particles by water or wind to elsewhere. Soil erosion by water and wind occurs naturally and continuously at low rates, depending on soil characteristics, soil morphology, soil exposure, climate, and vegetation cover. Because of this manifold of influencing factors, spatial and temporal variability in soil erosion is very large. Periodic large displacements may occur as a result of floods, earthquakes, land slides, glaciers and volcanic eruptions. Such episodic large displacements often have a dramatic environmental impact.

Soil erosion has impact on areas that lose soils and on areas that receive soil. Evidently, there are two sides of a coin. Areas that lose soil faster than new soil is formed, generally suffer from decreased productivity and other detrimental effects (on for example infrastructure and drainage). Areas receiving sediment are generally known for its fertility and productivity. This is the case in many deltas, flood plains, valleys, and accreting coastal zones, where floods deposit sediment from elsewhere. Also atmospheric depositions of dust contribute to the productivity of many areas. However, when floods, volcanic eruptions, or land displacements are huge, and dust storms have the dimension of a 'dust bowl', the effects become dramatic; the damage on ecosystem functioning, agriculture and infrastructure outweigh the positive effects on soil fertility.

Humans tend to accelerate erosion through deforestation, soil cultivation and poor soil management. Soil erosion resulting from poor land use is not new. History reveals that misuse of land and associated loss of top soil has been the main cause of the decline of many past civilizations. What is new however, are the accelerated rate and scale of soil erosion. The increased rate and scale of soil erosion is due to the rapid population increase during the last century, and concomitantly the increased deforestation, industrialization of farming practices and urban sprawl (as roads and housing developments mushroom into the country side with little or no concern about loss of soil). New is also that the topsoil of most agricultural land is enriched with nutrients and pesticides. Hence, both the rate of erosion and the ecological impact of sedimentation have increased worldwide through anthropogenic activities.

Changes in the Netherlands: from sediment accretion to a sinking basin

The Netherlands is situated in the delta of three major rivers, and has accumulated thick layers of marine, fluvial and aeolian sediments over millennia. During the last millennium, the process of sediment accretion has been facilitated along the seashore by humans, through barriers that break waves. The steady process of sediment accretion at an average rate of about 0.1 to 1 cm per year has been interrupted several times by periodic storm floods that have eroded large areas. Such regressions have had major impacts on the history and morphology of the Netherlands, but

when considering long-term trends they had relatively minor effects: the Netherlands has been a sediment accreting delta for millennia.
The desire to protect the country from periodic storm floods, which are generally associated with considerable erosion, led to the construction of dikes along rivers, lakes and seashore during the last millennium. These dikes protected the hinterland not only from storm floods but also from the regular flooding that previously brought a new layer of sediment each year, and that kept the delta accreting at a rate similar too or slightly higher than the mean sea level rise. As sea level continues to rise, now perhaps at accelerating rate due to climate change, dikes have to be made higher and higher, while the land sinks lower and lower (due to geodynamics). The paradox of building dikes is that the Netherlands has changed from a sediment accruing to a non-accruing delta. Because of the relative sea level rise, and because of some erosion in the hilly areas in the east and south (see below), the Netherlands has virtually become an eroding basin. Some have predicted that within 100 years, the western half of the country has sunk to a level that people have to move eastwards to a higher altitude (Bierkens, 2003, inaugural address University of Utrecht). Clearly, this is the issue for long-term sustainability of people living in a delta. The challenge perhaps is to let natural sediment accruing processes continue to do their work in some areas in the west. Evidently, this has major consequences for all settlements and infrastructure. It definitely needs further attention.

Apart from the long-term and large-scale trends indicated above, there are some long-term and small-scale trends in the Netherlands. There are regions that face wind and water erosion and sedimentation. Problems here consist of (i) on-field loss of fertile soil and damage of agricultural crops, (ii) off-field pollution and flooding of downstream areas, and (iii) deterioration of roads and water works. These effects are discussed further below.

Wind erosion

Wind erosion is defined as the physical transportation of soil particles by wind to elsewhere. Both, the removal of soil particles from the top soil, the process of transportation through the air and the subsequent sedimentation can have deleterious effects. In general, areas with sandy, peaty or loess soil types under arable crop cultivation on large fields without barriers are vulnerable to wind erosion. Inventories for Europe indicate that about 1 million ha in the western part of Denmark is sensitive to wind erosion (Prendergast, 1983). Similarly, about 170,000 ha in Sweden (Jönsson, 1985), almost 2 million ha in the northern part of Germany (Schäfer, 1991), 260,000 ha in United Kingdom (Prendergast, 1983), and 97,000 ha in the Netherlands (Eppink & Spaan, 1989) have been identified as sensitive to wind erosion.

In the Netherlands, the area sensitive to wind erosion is concentrated in the reclaimed peat land areas in the Provinces Groningen and Drenthe, and in the areas with sandy soils in the eastern part of Noord-Brabant. Smaller areas are situated in the northern part of Limburg, and along the dunes in Noord-Holland (Figure 12). It has been estimated that serious wind erosion for 5 to 10 days per year occurs every 3-4 years, and very serious wind erosion with >10 dust days per year occurs every 15

years (Eppink & Spaan, 1989). In the early 1980s, Eppink (1982) estimated the direct short-term wind erosion damage at twenty million guilders (about 9 million Euro) per year at that time. From a farms' survey at Exloërmond, Riksen & de Graaff (2001) found that wind erosion caused significant damage due to blistering of crops, loss of seedlings and filling of ditches by sand. They concluded that the economic costs due to wind erosion was about 500 € per hectare once every five years for sugar beet and rape (colza). Riksen et al. (2003) concluded that agricultural or environmental EU policies, within the framework of cross compliance, offer various policy tools to mitigate the wind erosion problems related to agricultural practices.

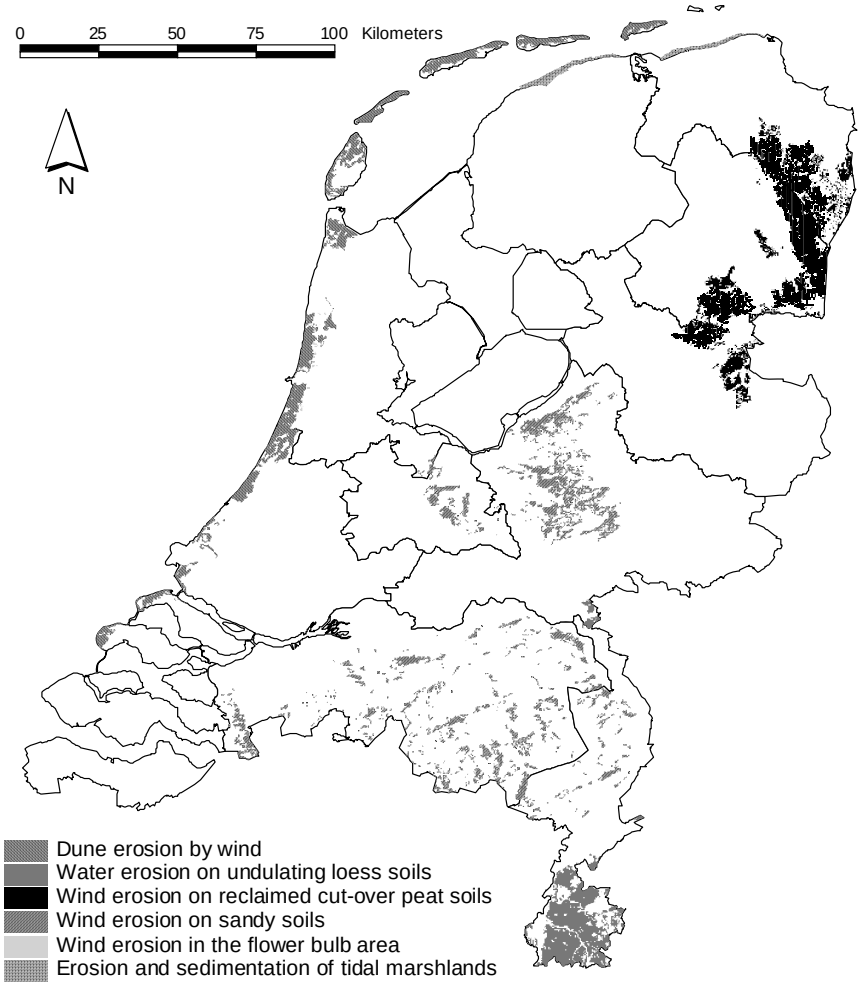

Figure 12: Location of the erosion types in the Netherlands (after Epping & Spaan (1998))

Water Erosion

Water erosion is defined as the physical transportation of soil particles by water to elsewhere. Generally, topsoil is removed by water erosion (run-off, via overland flow), but soil from deeper layers can be removed as well when the flow of water is channeled and is making incisions (gully erosion).Water erosion in the Netherlands is notable in the southern, hilly part of Limburg, and in the hilly area surrounding the village of Groesbeek (Gelderland). Recent studies showed that small agricultural catchments in these regions can produce runoff ratios of almost 50% on event-basis (De Roo et al., 1996, Van Dijk & Kwaad, 1996, Stolte et al., 1999). The total soil loss on this time scale can reach 1.3 ton/ha. Long-term monitoring studies indicate that the annual soil loss is about 14 ton/ha (De Roo, 1991). From a survey in the southern loess area, Schouten et al. (1985) concluded that over 300 locations are subject to damage due to water erosion. In this study, local municipalities have estimated that their annual costs due to erosion are up to one million guilders. Foreseen investments in measures to prevent damage reached up to almost 24 million guilders. Van Eck et al. (1995) concluded from their survey that the total annual costs are about 1.8 million guilders for local municipalities. They also surveyed costs of private persons, which amount up to 220 000 guilders per year for four municipalities.

In the Netherlands, about 600 000 ha contains slopes of ≥ 2%, and as such is susceptible to erosion. From a recent modeling study covering the whole of the Netherlands, it appeared that between 6 and 60% of the rainfall water does not infiltrate into the soil profile, depending on the soil type, antecedent soil water content and rainfall characteristics, but flows overland into lower lying ditches and streams (Stolte et al., 2000). The percentage of overland flow ranged from about 6% for dry soils combined with low-frequency rainfalls to 60% for initially wet situations in combination with high-frequency rain showers. Most susceptible soil types to overland flow are loamy, clay, and peat soils. These model outcomes have been verified by experimental measurements, but it should be noted that measuring actual runoff in the field accurately is very difficult, as the spatial variability is huge. The actual run-off depends amongst others on the local micro and macrorelief, and the type of land use and management activities.

Sedimentation by rivers in the delta

The three major rivers Rhine, Meuse and Scheldt transport sediment from the hinterland into the delta and the North Sea. Sediment concentrations depend on fluxes, and vary for the Rhine from 31 to 54, for the Meuss from 15 to 68, and for the Scheldt from 70 to 125 mg per liter. This translates to an average sediment load of 3,000,000 ton per year for the Rhine, 250,000 ton per year for the Meuse and 310,000 ton per year for the Scheldt. (Eppink, 1985). Much of this sediment ends up in the North Sea and Wadden Sea, but a significant fraction also in the distributaries. Haringvliet is a well-known collector of (contaminated) sediment from the river Rhine, and the Maasvlakte for dredged sediment from channels and harbours in the Rotterdam area.

Conclusion

The long-term fate of the Netherlands depends on the balance between sedimentation and sea level rise. Land reclamation and the building of ever higher dikes protects the country from periodic storm floods but also stopped the regular process of sedimentation. As a consequence, the Netherlands has changed from a sediment accruing delta subjected to natural sedimentation and erosion processes, to a well-protected but sinking basin. In the long run (one or a few hundred years), the economic and social costs of keeping dry feet in the western half may become too high for living. It may become profitable than to give the area back to nature and allow the natural processes of sedimentation and erosion to do their work again.

Wind erosion is a regional problem in the Netherlands, related to bare sandy soils in the winter half year. Specific measures can be taken to decrease the risk of wind erosion, e.g. tree lines, growing cover crops, applying surface coatings (animal slurry), minimum tillage techniques, and growing permanent crops. Part of such measures could be included in a package of cross compliance measures.

Erosion through run-off of rainwater is also a regional problem, related to bare soils in sloping areas in Limburg and some parts of the east. Also here, specific measures can be taken to decrease the risk of erosion, e.g. by growing cover crops, proper soil cultivation techniques, terracing, and by growing permanent crops. Part of such measures could be included in a package of cross compliance measures.

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6 Soil compaction

J.J.H. van den Akker

Soil ompaction is defined as densification and distortion of soil structure. Compaction leads to a decrease of total and air-filled porosity and of the permeability of soils. Compaction also lowers the productivity and biological activity of the soil. Furthermore, because of the decreased water infiltration and permeability, there is an increased risk for soil erosion and nutrient losses via run off and denitrification. 'Over-compaction' is defined as the visual degradation of soil structure and soil physical properties, which result in major reductions of soil qualities, such as crop yield and water infiltration rate. Compaction of soils is wide-spread phenomenon in the world, but is most prevalent at sites where heavy machinery. Wet soils are weaker and more prone to compaction than dry soils.

Soil compaction can be remediated (repaired) by freeze-drying and wetting-drying cycles, by (increasing) biological activity, and by cultivation techniques. Freeze-drying and wetting-drying cycles require that the whole compacted soil becomes periodically frozen and/or dry. Freezing proves to have only an alleviating effect in the topsoil.
Increasing biological activity requires that suitable substrates (organic matter) for the soil fauna, and perhaps even earth worms are applied to the compacted soil. Mechanical breaking of compacted soil is the common technique for remediation of compacted soil in practice. However, the improvement of soil structure by soil cultivation is greatly facilitated by freeze-drying cycles and increasing biological activity.

In arable land with annual ploughing, both topsoil and subsoil compaction should be considered. The subsoil includes the panlayer (in Dutch 'ploegzool') as the upper part of the subsoil. The panlayer is caused by the tractor tires driving on the subsoil during ploughing and by very high wheel loads. This panlayer is less permeable for roots, water and oxygen than the soil below it and thereby is key to the functioning of the subsoil. Contrary to the topsoil the subsoil is not loosened annually. Hence, subsoil compaction is an ongoing cumulative process, with in the long run as result a homogeneously compacted subsoil. The resilience of the subsoil for compaction is low and subsoil compaction is at least partly persistent. Therefore sustainable agriculture aims at prevention of subsoil compaction.

A 4 years lasting field experiment with silage maize on sandy soils (Alblas et al, 1994) showed that wheel loads of 50 kN decreased the yields of silage maize by 15 % on average, with a maximum yield reduction of 38% in a dry year on a soil with a deep groundwater table. Because of the compacted soil, roots of the maize did not go deep in the soil. They explored only a small volume of soil and hence, were therefore very sensitive to shortages of water (and nutrients). Detrimental effects of topsoil and subsoil compaction on crop production are often compensated by improved and deeper drainage and by increased supply of nutrients and water (irrigation). This leads to

extra use of water and nutrients and environmental pollution, which is less and less socially and politically accepted.

Table 6. Measured weights and wheel loads of 6 sugarbeet harvesters as measured during a sugarbeet harvesting demonstration in Watervliet, Belgium, 1999 (Van der Linden and Vandergeten, 1999) and minimal needed tire inflation pressures associated with these wheel loads.

Machine	Vervaet 17	Holmer Terra Dos	Riecam RBM 300-S	Ropa Tiger	Euro WKM Six	Big Kleine 40	SF
Gross vehicle weight (kN)	382	461	401	589	447	518	
Vehicle weight, empty (kN)	226	274	246	314	262	285	
Payload full tanker (kN)	156	188	155	275	185	233	
Wheel load full, left front (kN)	114	104	109	101	83	75	
Wheel load full, right front (kN)	114	99	124	94	64	73	
Wheel load full, left middle (kN)				109	76	93	
Wheel load full, right middle (kN)				117	65	79	
Wheel load full, left rear (kN)	77	129	76	84	92	92	
Wheel load full, right rear (kN)	77	130	93	84	68	107	
Inflation pressure, left front (kPa)	255	225	240	215	165	175	
Inflation pressure, right front (kPa)	255	210	290	195	95	165	
Inflation pressure, left middle (kPa)				205	140	140	
Inflation pressure, right middle (kPa)				220	165	85	
Inflation pressure, left back (kPa)	150	265	140	170	185	135	
Inflation pressure, right back (kPa)	150	270	190	170	110	195	

Many agricultural soils in the Netherlands display features of compaction. An unknown area of sandy soils and light loamy soils have over-compacted subsoils. These soils are frequently subsoiled, meaning that the subsoil is loosened by subsoil cultivation. However, loosened subsoil is vulnerable to re-compaction and the structure and soil physical properties of re-compacted soil are often worse than the original over-compacted soil. As a consequence, soils that are subsoiled once must be subsoiled every 3 to 4 years.

It has been suggested that the area of arable land that is subject to soil compaction is steadily increasing because wheel loads in agriculture are increasing. Fifteen years ago wheel loads of 50 kN were considered very high. Van der Linden and Vandergeten (1999) measured wheel loads of up to 130 kN during a sugar beet harvester demonstration in 1999 (Table 6). Modern self-propelled slurry tankers with injection equipment with wheel loads of 90 – 120 kN are currently used. The largest tires available with inflation pressures of about 200 kPa are needed to carry such high wheel loads. The consequence is that subsoils tend to become increasingly compacted to greater depth. Ehlers et al. (2003) reported about severe impacts of heavy sugar beet harvesters on loess soils in Lower Saxony in Germany. On commercial farmland the dry bulk density of the subsoil proved to be significant higher in 2002 compared with measurements in 1976, 1988 and 1999 (Figure 13).

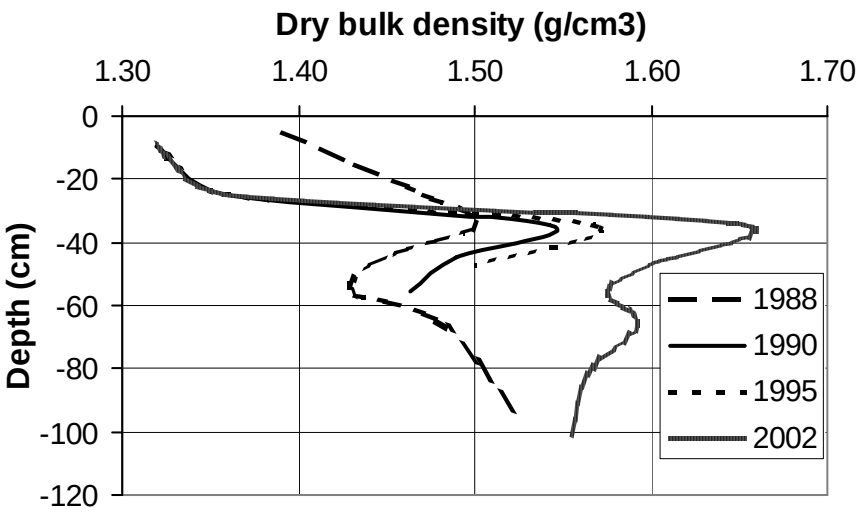

Figure 13. Increase of dry bulk density of a loess soil by increasing wheel loads in time (1988 - 2002). Bulk densities higher than 1.6 g/cm³ result in a strong decrease of rootability and soil water conductivity (Ehlers et al., 2003).

So far, the self-repairing capacity of clayey subsoils by shrinkage during drying and by biological activity has been considered to be sufficient to repair compaction. Experiences in Germany (Ehlers et al., 2003) do suggest however, that this self-repairing is not always effective and efficient. Further, subsoiling of clay soils is more difficult and requires much more energy and is less successful than subsoiling of sandy soils. This suggests that subsoil compaction needs to be prevented as much as possible. Most farmers on clay and loam soils know the risks of and problems associated with soil compaction and subsoil compaction. But the short-term economic pressure to increase the scale of farming and to lower costs is often much larger than the long-term benefits of preventing soil compaction and subsoil compaction.

In general, soil compaction is not a topical issue. There is also not much awareness and attention for compaction and subsoil compaction in governmental policy and research. Experimental field research concerning compaction of clay and loam soils in practice has not been carried out during the last 15 years in the Netherlands. As a result, there is no empirical information about the scale, extent and seriousness of soil compaction in practice. There is also no monitoring program to identify trends in practice. All current information about soil compaction is based on research carried out in neighboring countries.

Evidently, the best strategy to alleviate soil compaction is to prevent soil compaction. Proper drainage, proper timing of soil cultivation, and of seeding and harvesting practices, and lowering wheel loads and tire pressure, and increasing tire size and amount of tires are the tools to be used to prevent soil compaction. Despite this many tools and options to minimize the risk on compaction, experiences in Europe suggests that these tools are not used much. Van den Akker et al. (2003) concluded that the European subsoils are more threatened for compaction than ever in history. Research from neighboring countries provide evidence that soil compaction is

increasing in scale and extend, but there are no data to substantiate such trends for the Netherlands.

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7 Soil biodiversity

J. Bloem, J.H. Faber (Alterra) and T. Breure (RIVM)

When the Netherlands signed the Convention on Biological Diversity in Rio de Janeiro in 1992, they committed themselves to preserve biological diversity on their territory. The application of the treaty to policy and research receives considerable attention and has been formalized in policy documents such as 'Nature for people, people for nature' (LNV, 2000), the Fourth National Environmental Policy Plan (VROM, 2000), the document 'Sources of Existence' (LNV, 2002), and other documents (TCB, 2003; VROM, 2003). The development of a national policy on biodiversity is currently at the initial stage, during which creating a sound scientific basis is pivotal and environmental criteria are not yet established.

The biodiversity in soil – in terms of species diversity – is very large. The number of bacteria species per gram of soil for instance, is estimated at around 10,000. Therefore the soil has sometimes been called *the poor man's tropical rain forest*. The exact species richness of soils in the Netherlands has not been established yet, because of the difficulties, limitations and/or specialization needed to isolate and identify cryptobiota. Relationship between the species diversity, soil type and environmental conditions have also not been established yet, except for a few soil organisms. Hence, the knowledge needed to built sound policies for soil use and management is still very limited.

Is there a biodiversity problem in the Netherlands?

Despite the limited insight in the diversity of micro organisms in soils, there is evidence that biodiversity has been altered by the (intensive) use of the soil. In general, this change has been qualitative, i.e., a change in species composition rather than quantitative in the sense of a decrease in species diversity. Impoverishment will become important under extreme conditions, i.e. through soil acidification and pollution, and intensive soil cultivation. For example, in acid soils polluted by heavy metals, a significant reduction of 20 to 40 % of the most abundant species of bacteria was observed. This was accompanied by an even greater decrease of bacterial biomass and activity (50 to 90 %). Not only the number of species is therefore important but also the functioning of the soil community. There is also some evidence that the functional stability of soils is lower in polluted soils. Following experimental disturbance (stress on stress) the resistance and resilience was greatest in unpolluted soils (Tobor-Kaplon *et al.*, 2004). There are also indications that soil life is more stable in organic agriculture than in conventional agriculture (e.g. Griffiths *et al.*, 2001; Mulder *et al.*, 2003).

Prevention of further deterioration and restoration of biodiversity in agricultural areas may contribute considerably to the accomplishment of national biodiversity policy goals, especially agriculture land covers a large area in the Netherlands. At present, it is unclear to what extent soil biodiversity may contribute to the quality of themes under the *European Soil Strategy* such as soil structure and organic matter.

What is evident, however, is that soil organisms are crucial for these subjects, as well as for the improvement of soil quality. There is sufficient (qualitative) evidence that soil organisms contribute to the improvement of soil structure.

Recently it has been demonstrated that the composition of the soil fauna is a key factor to the development of young vegetation during the process of changing land use (De Deyn *et al.*, 2003). Mycorrhiza fungi also play an important role in the development of a diverse vegetation. As a consequence the impoverishment of soil biodiversity will pose risks to the management of organic matter and soil structure. This will matter mostly in agricultural land and in agricultural land converted to nature conservation areas (these soils often lack structure and contain little organic matter).

Biodiversity and sustainable agriculture

The stimulation and exploitation of the sustainable use of agrobiodiversity is considered of key importance for development towards a sustainable, socially accepted and appreciated agriculture (*people*, *planet*, *profit*). For the transition to more sustainable agriculture, it is necessary to increase the biological suppression of soil borne diseases in order to reduce the use of (chemical) pesticides. In this process the (microbial) biodiversity plays an important role. When less pesticides and chemical fertilizers are used, and less manure with less nitrogen and phosphate is applied, soil life will definitely have a bigger role in nutrient cycling and prevention of disease. In that case nutrients will become available to crops mainly by mineralization processes and by symbiosis between plants and fungi (mycorrhiza) or nitrogen fixing micro organisms. That is why changing agriculture is accompanied by a change of life in the soil.

An important question is how and how quickly soil communities change as a consequence of changing agricultural practices (for example reduced fertilization, broader rotation schemes) and what this means for nutrient cycles and soil health. Currently, soils in the Netherlands contain very few fungal hyphae. This has probably been caused by the presence of intensive agriculture over many years which results in the disappearance of fungi that metabolize poorly degradable substances and the disappearance of mycorrhiza fungi that improve the uptake of nutrients by plants when the soil contains few minerals. There are clues that for both sustainable agriculture and nature restoration, an increase of fungi and fungi-eating organisms in soil is required.

With current methods only the diversity of the most abundant species is measured. Rarer species remain undetected. To improve the monitoring of these species molecular techniques are needed. Because of the enormous diversity of soil species, for practical reasons the bulk of scientific research in this field is focused on *functional* biodiversity. This includes (groups of) organisms that make a relatively large contribution to the properties of the soil that matter most to land use or to the functioning of the ecosystem as a whole, i.e., to *ecosystem health* and *life support functions* (also called *ecosystem services*). The organizational level implied in this research is often higher than the species level. There is still insufficient scientific understanding of the

requirements of soil biodiversity to support the mentioned functions or services, both qualitatively and quantitatively.

The European Soil Strategy is focused on the sustainable use of the soil. Key words are sustainability and land use. In addition the idea is that the ecological status of the soil, and the changes therein as a consequence of human activities, provides insight into the degree of sustainability of soil use. Five working groups are implied in preparing the European Soil Strategy. One of those was initially called 'Soil Organic Matter' but changed its name to 'Soil Organic Matter and Biodiversity' to indicate that soil biodiversity is equally important compared to the content and properties of soil organic matter. The Biological Soil Indicator, as developed in the Netherlands, is seen as an example for other European countries by the working group. Because biodiversity is a very complex issue by nature, it is hard to establish definitive criteria for it. Monitoring, maintaining and fostering biodiversity is already difficult enough for the time being. The basic goal for soil biodiversity is that there should be no local reduction. To this extent, soil diversity is conceived in a broad sense. It includes species diversity and relative species abundance but also the activity of organisms and the diversity of their functional characteristics.

Together with its partners Alterra and Wageningen University, and in commission of the Ministry of Spatial Planning, Housing and the Environment (VROM), the Netherlands Environmental Assessment Agency (RIVM) focuses its research on ecological quality criteria for soil (Breure *et al.*, 2003; Bloem *et al.*, 2004). Based on the data collected thus far, the establishment of such criteria is by now considered realistic for a limited number of combinations of soil types and land use.

Data sources and institutions involved

The largest database with respect to functional biodiversity in rural areas has over the past years been composed within the framework of the development of a Biological Soil Indicator. This was done for the national soil monitoring network in commission of VROM and the Ministry of Agriculture, Nature and Food Quality (LNV) by RIVM, Alterra and the Department of Soil Quality of Wageningen University. Inventories were made of a limited number of taxonomical groups that are assumed to be relevant for the most important life support functions of the soil (among which the breakdown of organic matter and soil structure). The current data set consists of data from farming areas (arable and pasture land) and a certain category of forest soils. The monitoring program should be extended to include other types of ecosystems and should be further elaborated to facilitate policies for optimization and management of functional soil biodiversity: improvement of soil structure, management of organic matter, nutrient cycles and disease suppression.

The work on the Biological Soil Indicator has thus far mostly been focused on deriving the possible regional and national goals for soil biodiversity development. A next step will be to generate location-specific applications, for instance when farmers want to compare parcels of land with different management practices. The influence of land management on the soil biodiversity will also receive increasing attention in the future.

Another database, currently being developed by the National Museum of Natural History 'Naturalis', is the species list for the Netherlands (due by the end of 2003). But this list (viruses, bacteria and microfungi are not included) will probably contain insufficient ecological and geographical information to be instantly used to support policies.

Research on functional biodiversity at Alterra and Plant Research International is financed through different channels by, among others, the Ministry of Agriculture, Nature and Food Quality (LNV), the Ministry of Spatial Planning, Housing and the Environment (VROM) and by the Dutch funding agencies SKB, NWO and TRIAS. Soil Strategy themes such as soil structure and organic matter cycling in soil currently are not areas for special attention in this research. The emphasis is rather on natural soil fertility, disease suppression and the functional stability of soil communities. In addition, research on functional biodiversity is conducted by RIVM, Wageningen University (sections of Soil Quality, Nematology, Biological Farming Systems, Phytopathology, Microbiology), the Netherlands Institute of Ecology (e.g. nature development), The University of Utrecht (e.g., environmental sciences), the Vrije Universiteit in Amsterdam (e.g., soil ecology), and the Louis Bolk Institute (organic farming).

At the international level work is done on indicators for monitoring of biodiversity and soil quality (OECD, FAO, EU-COST, EU task groups). The OECD and the FAO jointly develop indicators for agrobiodiversity and consider agrobiodiversity as crucial to soil fertility and food security. In addition, soil biodiversity is regarded as 'production supporting biodiversity' (e.g., OECD, 2003; FAO, 2002). The OECD currently also elaborates on a questionnaire that it intends to use to let member countries report on the progress on agrobiodiversity development.

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8 Degradation of peat lands

J.J.H. van den Akker

Peat oxidation and subsidence

World wide, peat lands cover about 420 million ha and contain 20-30% of the world's soil organic carbon. Peat lands are extremely vulnerable to changes in water management, land-use and climate. Over the last centuries, anthropogenic pressure for land in Europe has resulted in the reclamation of large areas of peat swamps to make them suitable for agriculture or other land uses. The required drainage to reclaim peat lands results in subsidence and degradation of peat soils. The rate of subsidence is variable and depends on a number of factors, including peat type, drainage, climate, land use, and history.

There are three processes that contribute to subsidence: (1) consolidation; (2) loss of organic matter due to biochemical decomposition (oxidation) and (3) shrinkage by drying. In the first 5 to 10 years after drainage of peat soils a major part of the subsidence is caused by consolidation of the peat layers and permanent shrinkage of the upper peat layer. However, after consolidation and the creation of a ripened upper peat layer the main factor responsible for subsidence is oxidation. The continuing decomposition of organic matter causes a continuing subsidence of peat soils. The water level of the ditches are regularly adjusted to the lowered soil surface, so that the processes of oxidation and shrinkage continue until virtually all peat has been decomposed.

Oxidation is the main factor responsible for subsidence over the long term. Typical peat subsidence rates range from a few millimetres to as much as 5 centimetres per year depending on drainage and climatic (i.e. temperature) conditions. Subsidence of one centimetre per year equates to an emission of about 30 tonnes of CO_2 per hectare per year. Subsidence may also damage infrastructure and buildings and water management becomes more complex and expensive.

Peat land conservation

Many wetlands are difficult to preserve as 'wetland' because subsidence of adjacent agriculturally improved (i.e. drained) land results in 'islands of peat land' surrounded by lower elevation agricultural lands. The net effect is a constant drainage of the peat land. As a result of drainage of agricultural peat soils, semi-natural or natural peat lands are becoming rare. On the other hand some peat lands have been in agricultural use for centuries and are part of European cultural heritage and represent highly valued landscapes and meadow bird regions. Especially the Western peat areas of the Netherlands represent a landscape that is part of the European cultural heritage. Peat lands also act as natural stores and filters affecting water quantity and quality important for human communities throughout Europe. Thus, peat lands are a significant issue in the Ramsar Convention, the Framework Convention on Climate Change, the Convention on Biological Diversity, and other international instruments and agreements.

In the Guidelines for Global Action Plan on Peat lands (GAPP)[3] of the Ramsar Convention it is stated that the wise use, conservation and management of the World's peat lands assets are constrained by limited scientific and technical information and by the effects of economic, socio-cultural and environmental factors. The Ramsar Bureau plays an active role in the implementation of the Pan-European Biological and Landscape Diversity Strategy and in the implementation of the Convention on Biological Diversity.

Extensivation of agriculture, the interest for organic farming, production of region specific agricultural products, recreation, protection of fresh water resources, conservation of important wetland bird and floral habitats, storage of water of floods are considered as factors and as an opportunity to combine a socio-economic viable countryside with restoration of peat lands and extensive grasslands. The delicate balance between agriculture, nature, landscape, environment requires improved knowledge to support the decision-makers request for effective strategies to protect and manage peat lands against the pressures of changes in climate and land-use management.

Peat land degradation in The Netherlands

The area peat land in the Netherlands is about 210 000 ha and is mainly used as permanent grassland for dairy farming. Increased drainage of peat land areas started around 1960 when the economical situation of dairy farming in the peat areas became worse because the high ground water levels made modern agriculture with heavy machinery and many cows per hectare impossible. Therefore in the years 1960 – 1970 ditch water levels were lowered from a mean of 20 – 30 cm minus surface prior to 1960 to 60 cm minus surface in the Western peat areas and up to 120 – 150 cm minus surface in the Northern peat areas. A rule of thumb states that every 10 cm lowering of ditch water level results in an extra subsidence of 1 – 2 mm per year. This means that in the Western peat areas the subsidence rate was doubled and in the Northern peat areas became about 4 times higher than in the past.

Generally, there are significant differences in subsidence within a polder, because the water level of not all ditches are regulated at the same level, distances between ditches can be different, some fields can have a protective clay layer, parts of the polder have seepage, etcetera. With time, differences in subsidence and subsequent adjustments (fine-tuning) of water levels in ditches result in a very complicated hydrological situation which makes water management increasingly difficult and expensive. The subsidence of drained agricultural peat areas and subsequent lowering of water levels in ditches may also cause drainage of surrounding non-agricultural areas, which then may lead to increases in the incidence of drought and to damage of buildings and infrastructure.

The rate of subsidence depends on the hydrological situation, peat type and the presence of clay layers. It ranges between 2 – 25 mm/year, and is on average 8 mm/year in The Netherlands. The oxidation of peat results in an estimated mean

[3] Ramsar Scientific and Technical Review Panel, 2001. 10th meeting of the Scientific and Technical Review Panel, Gland, Switserland, 27-29 June 2001. www.ramsar.org/strp_10minutes.htm

CO_2 emission of 18 Mg CO_2 per hectare per year. The total contribution of peat soils to the CO_2 emission of The Netherlands is estimated at 5 – 15 Tg CO_2 per year (chapter 3)..

The oxidation of peat soils depends strongly on the groundwater level in summer. In summer evapotranspiration exceeds precipitation. This results in a lowering of the groundwater level because the infiltration capacity of water from the ditches into the peat soil is low. All peat soil above the groundwater level is exposed to atmospheric oxygen and to accelerated biological degradation of the organic matter in peat. The low groundwater levels in summer and the fact that biological degradation strongly depends on temperature, causes that more that 80 % of the total peat oxidation occurs in the summer half year.

Drainage of peat soils indirectly also contributes to eutrophication of surface waters. Upon drainage and the mineralization of peat, large amounts of nitrogen (100- 300 kg N per ha per year) and also phosphorus are released and part of these nutrients may leach to the surrounding surface waters in autumn and winter when groundwater level are shallow. The mean N and P concentrations in peat land polders in the Netherlands are on average rather high, which reflects the eutrophic nature of the peat and the influence of seepage.

Raising the groundwater level to 35 cm or to even shallower depth will decrease the rate of subsidence but will also decrease the possibilities for farming. It has been estimated that raising the groundwater level from a mean of 60 to a mean of 35 cm below surface decreases the productivity of the land and farm income by approximately 270 Euro per ha per year, which is equivalent to 11,000 euro per farm per year. This loss is considered to much to survive economically, without additional compensation. The nature value of the land increases when groundwater is shallower, and this may become an additional income source in the near future (cross compliances, agri-environmental regulations).

Current problems in the peat areas are highly complex. A gradually subsidence and a gradually adaptation to a lowering of the surface level has been common feature for many centuries and the inhabitants have learned to cope with that situation. However, the increased subsidence rates during the last 3 to 4 decades are unprecedented and are causing major problems. Technical solutions should focus on increasing the groundwater levels in the summer, because more than 80% of the subsidence is caused in the summer half year. Increasing the groundwater levels via increasing the water level in ditches is only partly effective, because the lateral infiltration of water from ditches into the soil is very slow. A technique that is now tried out is infiltration of water via submerged drainage. However, this solution requires further study on its effectiveness, sustainability and effect on water management and water quality.

9 Soil salinization

O. Oenema

Soil salinization is defined as the increase in the contents of soluble salts (mainly sodium, chloride, sulfate, and carbonates) in soil, groundwater and surface waters. Soil salinization deteriorates soil structure and decreases productivity through salt-induced stresses (drought, malnutrition, and chlorosis). It affects crops that are sensitive to salt stress (vegetables, potatoes) and fresh water fauna and natural vegetation.

Soil salinization is not yet a big problem in the Netherlands, because of the large precipitation surplus, which flushes excess salts from fertilizers, manures, compost, salt seepage water and atmospheric deposition ultimately to the sea. Most soils are also permeable, which facilitates leaching of excess salts to the groundwater and surface waters. However, half of the Netherlands is situated below sea level, and this makes this area sensitive to salinization through seepage of sea water and brackish groundwater.

Soil salinization occurs locally in dry summers in the low-lying areas in the north-western half of the Netherlands. Problems occur in some polders in the Provinces of Zeeland (Schouwen Duivenland), Zuid- en Noord-Holland, Friesland and Groningen, through seepage of salt or brackish groundwater. Seepage is increased in dry summers when groundwater level drops, which is in part accelerated through groundwater extraction for purposes of irrigation, drinking water supply and industrial activities. Seepage of brackish groundwater is especially large in low-lying polders.

Local problems of soil salinization can be relieved through water management, and soil and crop management. Water management is very important, as some crops are particularly sensitive to irrigation of salty water (with high chloride content). Water authorities (waterschappen) and various farmers monitor the concentrations of salts (chloride) in canals and ditches, to allow prediction of salt damage upon irrigation. Crops sensitive to salts can not be grown in such condition.

There are various arguments to suggest that salinization will become a much bigger problem in the near future. Seepage of brackish groundwater will increased as a result of both subsidence and sea level rise. The surface level of the Netherlands subsides because of its position in the delta of the large rivers and as a relict of the ice ages. In various parts of the Netherlands, subsidence is increased further through peat land degradation (chapter 8), and exploitation and extraction of natural gas, salt and soil, gravel and groundwater from the subsoil. The sea level rises as a consequence of climate change. exploitation, relative to the mean sea level (rise). The increased subsidence and the increased sea level rise will lead to increased intrusion of salt and brackish groundwater in the soil and surface waters.

The agronomic and ecological impacts of increased salinization can be large. Some crops sensitive to salt may not be grown, or may not be irrigated with surface water. On the other hand, increased salinization may open up the way to so called 'salt-water agriculture', producing high-value vegetables. Intrusion of brackish water in surface waters will dramatically change the ecology of these surface waters, as fresh water aquatic life will not survive in brackish water. This will lead to an impoverishment of the ecological value of surface waters.

10 Soil covering

O. Oenema

Soil covering is defined as sealing of the soil surface, which effectively reduces the exchange of water, matter and life between soil and atmosphere to zero and results in a virtually dead (or at least severely disfunctional) soil. Water and matter that are deposited on covered soils move sooner or later to central collectors or to the borders of the covers. Hence, any deposited matter is concentrated on a smaller area; the covered soil is not participating in exchange and natural attenuation processes. Evidently, when all soils are covered, the terrestrial biosphere has gone. But what is the maximal acceptable (tolerable) coverage in the world, in the Netherlands? This question has not been answered yet.

Soil covering occurs in urbanized and industrial areas, roads and glasshouse horticulture and floriculture. Approximately 15 % of the surface area in the Netherlands is urban, industrial or infrastructural (roads), which is equivalent to approximately 5000 km^2. A significant fraction (10 to 50%) of this area is soil-covered (500 to 2500 km^2). Glass houses cover approx. 250 km^2 (25.000 ha).

Summarizing, a relatively large area of soil in the Netherlands is partly or completely covered (sealed). Coverage changes the flow of water and matter, but there are no signals from practice that possible problems related to these changes cannot be solved technically so far. There are no standards or norms for an acceptable level of covered areas. Increasing coverage will ultimately contribute to the collapse of the terrestrial biosphere.

Annex 1 Overview of the composition of topsoils (0-30 cm) in the Netherlands. The results for pH-KCl, and the contents of organic matter, clay and heavy metals are presented as minimum and maximum values and as percentile values (10, 50 and 90%), for all soils, and for peat, sand, loam and clay soils (source: Brus et al., 2002).

All soil types

	Org. Matter	clay	pH-KCl	Cd	Pb	Hg	As	Cu	Zn	Ni	Cr
	%	%		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
min	0.3	0.0	2.5	0.00	0.5	0.00	0.4	0.0	1.5	0.5	0.6
10%	2.1	1.8	3.9	0.13	10.2	0.04	2.0	4.0	14.7	2.0	5.4
50%	5.9	12.6	5.5	0.31	23.0	0.10	10.0	13.0	46.0	13.1	22.7
90%	25.9	31.4	7.4	0.92	75.0	0.29	19.9	36.9	140.0	31.2	64.5
max	97.6	54.2	8.7	45.10	952.7	13.80	180.0	270.0	1700.0	127.3	410.0
n	3938	3342	3859	3431	4068	1844	1981	3328	3392	1755	2098

Peaty soils (OM > 15%)

	Org. Matter	clay	pH-KCl	Cd	Pb	Hg	As	Cu	Zn	Ni	Cr
	%	%		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
min	15.0	0.0	2.5	0.09	10.0	0.04	0.5	1.7	7.7	0.8	2.5
10%	16.9	3.2	4.2	0.31	26.0	0.10	3.3	11.0	37.0	3.9	10.0
50%	25.5	19.3	5.0	0.74	61.0	0.18	10.0	27.3	105.0	18.8	30.0
90%	51.0	36.0	6.3	1.49	170.0	0.43	19.0	64.0	202.0	37.1	70.0
max	97.6	54.2	7.5	45.10	952.7	13.80	180.0	270.0	1700.0	75.0	410.0
n	801	760	775	592	799	436	419	751	757	487	541

Sandy soils (clay < 8%)

	Org. Matter	clay	pH-KCl	Cd	Pb	Hg	As	Cu	Zn	Ni	Cr
	%	%		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
min	0.3	0.0	2.8	0.01	0.5	0.00	0.4	0.2	2.0	0.5	1.0
10%	1.8	0.9	3.6	0.10	8.9	0.02	1.3	2.1	10.1	1.1	5.0
50%	5.0	2.6	5.3	0.28	17.0	0.07	3.0	9.4	26.1	4.0	10.5
90%	10.3	6.2	7.4	0.52	38.1	0.18	10.0	18.4	53.0	10.7	26.8
max	14.8	8.0	8.7	17.20	849.7	8.52	109.0	49.6	799.4	127.3	406.7
n	1015	1129	1063	781	1068	628	542	776	826	376	640

Loamy and silty loam soils (8% < clay < 25%)

	Org. Matter	clay	pH-KCl	Cd	Pb	Hg	As	Cu	Zn	Ni	Cr
	%	%		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
min	1.1	8.0	3.7	0.04	3.0	0.01	1.4	0.2	10.2	1.0	7.0
10%	1.9	10.2	5.7	0.20	13.0	0.05	6.7	7.0	37.1	8.6	17.0
50%	3.5	16.2	7.2	0.35	23.0	0.10	12.2	14.3	59.0	15.2	35.0
90%	9.7	22.8	7.5	0.74	47.4	0.23	20.0	29.4	112.0	23.2	65.9
max	14.9	25.0	8.5	4.50	250.0	1.50	110.0	165.0	638.6	57.5	175.0
n	1004	1045	929	932	1038	537	692	758	760	470	485

Clay soils (Clay > 25%)

	Org. Matter	clay	pH-KCl	Cd	Pb	Hg	As	Cu	Zn	Ni	Cr
	%	%		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
min	1.5	25.0	3.7	0.09	5.0	0.01	3.1	6.0	44.0	8.0	17.0
10%	2.8	26.3	5.2	0.20	20.0	0.06	10.0	10.2	61.0	16.0	26.0
50%	5.9	30.8	7.1	0.40	31.0	0.11	15.9	17.0	85.5	25.3	42.0
90%	12.3	40.5	7.4	0.84	59.8	0.31	23.0	32.0	146.8	37.2	96.0
max	15.0	52.0	7.6	2.96	279.5	0.99	58.0	108.0	496.0	60.6	130.0
n	366	366	331	333	366	231	284	272	272	198	197

Referentie

Brus, D.J., J.J. de Gruijter, D.J. Walvoort, F. de Vries, P.F.A.M. Römkens & W. de Vries, 2002. Landelijke kaarten van de kans op overschrijding van kritieke zwaremetaalgehaltes in de bodem van Nederland. Alterra rapport 124, Wageningen.