NATIONAL INSTITUTE OF PUBLIC HEALTH AND THE ENVIRONMENT

BILTHOVEN, THE NETHERLANDS

Report no. 481505006

Generalized Soil Map of Europe

Aggregation of the FAO-Unesco soil units based on the characteristics determining the vulnerability to degradation processes

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March 1996

Research carried out in the framework of the project, 'Pan-European State of the Environment, on request of the European Environmental Agency's Task Force by, and under the responsibility of, RIVM, the National Institute of Public Health and the Environment and under the direction of the Directorate of International Affairs and Stratigical Planning of the Directorate General of Environment, Ministry of Housing, Spatial Planning and Environment.

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Preface

In the framework of the Dobris project a soil map has been created which should give a general idea of the vulnerability of soils to different types of soil degradation. The map was published in the report of the European Environmental Agency 'Europe's environment; the Dobris Assessment' in September 1995. The current report provides the scientific background information and assumptions used to create this map.

Acknowledgements

Valuable comments and suggestions regarding the aggregation of soil units have been made by Hans van Baren, Otto Spaargaren and Roel Oldeman of the International Reference and Information Centre (ISRIC), by Raoul Dudal of the Catholic University of Leuven (KUL) and by Ólafur Arnalds of the Agricultural Research Institute of Iceland (RALA). For the estimation of the vulnerability of soil to the different degradation processes, I am very grateful for the comments and suggestion made by Ben van der Pouw from the Winand Staring Centre (SC), Godert van Lynden of ISRIC and Ton van der Linden and Jaap Willems of the National Institute of Public Health and the Environment (RIVM). I also wish to thank Anne Teller from the Task Force of the European Environmental Agency and Ruth de Wijs-Christenson (RIVM) for their editorial comments. Finally, my thanks go to Kees Schotten (RIVM) and Eddy Scheper (ARIS) for the production of the maps.

Dico Fraters, 10 January 1996.

Contents

Summary

The FAO-Unesco soil units of Europe have been aggregated into categories of soils with similar soil characteristics (soil depth, stoniness, texture, acidity, etc.) which are of importance to the vulnerability of the soil to the major degradation processes. The major soil degradation processes in Europe are water and wind erosion, compaction, acidification and pollution of groundwater and ecosystems. The resulting 11 categories have been clustered into four sets according to their similar behaviour in response to soil degradation processes. It is estimated that about 15% of the soils of Europe are highly vulnerable to all major degradation processes and 30% highly vulnerable to 3 of the 4 degradation processes.

Samenvatting

De bodemeenheden die op de Europese bodemkaart (FAO-Unesco, 1981) voorkomen, zijn geaggregeerd tot 11 categorieën van bodems met vergelijkbare bodemkarakteristieken. Deze karakteristieken zijn van belang bij het schatten van de gevoeligheid van de bodem voor de belangrijkste bodemdegradatie processen. Het betreft hier, onder andere, de volgende bodemkarakteristieken: bodemdiepte, stenigheid, textuur en zuurgraad. De belangrijkste bodemdegradatie processen in Europa zijn wind- en watererosie, compactie, verzuring en verontreiniging via de bodem van het grondwater en het ecosysteem met milieuvreemde en milieu-eigen stoffen. De 11 bodemcategorieën zijn samengevoegd tot 4 groepen van bodemcategorieën die een vergelijkbaar gedrag vertonen ten aanzien van bodemdegradatie. Op basis van het voorliggende materiaal wordt geschat dat 15% van het Europese landoppervlak zeer gevoelig is voor alle vormen van bodemdegradatie. Ongeveer 30% is zeer gevoelig voor 3 van de 4 vormen van bodemdegradatie.

1. Introduction

Soil is a vital resource for the production of food, fibre and other necessities of life. In considering the soil as a production factor, not only for biomass production but also where the soil is used for other functions like filtering, full account should be taken of the fact that soil is formed so slowly that it is essentially non-renewable. All soils need to be managed in ways that will maintain their usefulness.

Sustainable management of soils takes account of the knowledge that soils are different in many respects, no matter what the scale of interest is. For example, in the USA this knowledge is already used in agriculture. Soil-specific crop management (SSCM) allows farmers to adapt their management practices to the many variables in the field, possibly increasing productivity and decreasing fertilizer and pesticide costs (Robert, 1993).

The main object of this report and map is to show the wide variety of soils in Europe in respect to their behaviour in response to soil degradation processes such as soil erosion, compaction, acidification and pollution.

The FAO-Unesco soil units (FAO-Unesco, 1974; 1981) have been aggregated into 11 categories using criteria such as soil depth, topsoil texture, topsoil organic matter content, soil moisture regime, occurrence of salt and depth of the groundwater table. All are characteristics determining whether soils are vulnerable to soil degradation or not. The present map is not a vulnerability map, it is a generalized soil map. Vulnerability has to be specified with respect to agents, causes and effects (Desaules, 1991). Nevertheless the soils belonging to the same soil category do, in many respects, behave in a similar way to soil degradation processes, and this map can assist us in learning, in general terms, which areas in Europe are vulnerable to the different types of soil degradation.

It should be stressed that areas on the generalized soil map presented in this report contain, sometimes to a high degree, map units which belong to a different soil category. This map is largely based on the NOAA Digital Soil Map of the World (1991). This NOAA map contains only dominant soil unit information, and therefore aggregation of soil units was the only option. As will be shown in the next chapter, by selecting a region and using a different aggregation method within the selected region, some of the drawbacks of the NOAA map have been overcome.

The current generalized soil map of Europe can be easily ameliorated if the digital version of the Soil Map of the World, Volume V Europe (FAO-Unesco, 1981), is available, by using the information presented in this report. In this case, soil phases (e.g. stoniness and salinity), soil texture and slope will not have to be estimated. An improved generalized soil map can be created by an overlay of the several 'maps'. In future, a better map can be created if a European soil map becomes available on a scale of 1 : 1,000,000 with three categorical levels (Major Soil Group, soil unit and soil subunit), already available for the EC and middle Europe (CEC, 1985; ISSS, undated). The last one, the soil map of middle Europe, is not yet available in digital form. The Soil Map of the World (FAO-Unesco, 1974) has two categorical levels. The effects of the differences between the FAO-Unesco map (1981) and the CEC map (1985) on the estimation of derived soil characteristics are, for example, discussed for the organic matter content in Fraters et al. (1993). They also found some regions with totally different classified soils. More impurities, recorded in the FAO-Unesco soil map of 1981, are illuminated in Appendix VI. A generalized soil map of Iceland, which deviated strongly from the FAO-Unesco map, was received from RALA (Agricultural Research Institute of Iceland).

Recently, the FAO (1991) published a soil map of the world with a scale of 1 : 25,000,000; this could also been seen as a generalized soil map. The objective of this map was to promote a wider appreciation of the distribution of the soils and of the different forms of management which they require if they are to produce necessary commodities without loss of production capacity. Like the map presented in this report, this map was based on the Soil Map of the World 1 : 5,000,000 (FAO-Unesco, 1971-1981). As the authors of this 1991 FAO map state: it is a rather simplified map based on aggregation of Major Soil Groups, and therefore holds a strong pedological classification, based for a large part on soil formation processes. In the present project the objective is to create soil categories which consist of soils with a more-or-less similar behaviour to soil degradation processes. Another related map is the GLOSAD map (Oldeman et al., 1991). This map presents a global assessment of the status of human-induced soil degradation. It does not indicate whether soils are vulnerable or not to soil degradation processes, but it gives an estimation to what extent they are degraded at present and what the main processes are.

In Chapter 2 the methodology of aggregation of the soil units into soil categories will be discussed and estimation of soil characteristics will be explained. In Chapter 3 the resulting 11 soil categories will be treated separately. The result of the estimations will be given and similarities of and differences between the soil units within a specific soil category will be discussed. In the fourth and last chapter vulnerability of the different soil categories to the main soil degradation processes in Europe will be discussed in general.

2. Methodology of aggregation of the soil units

For each of the dominant soil units occurring on the European part of the World Soil Map (NOAA, 1991; FAO-Unesco, 1981) soil characteristics have been estimated using the methodology explained in §2.2. The result are presented in Appendix III. Based on these characteristics soil units have been aggregated (see next section and §2.3) using the aggregation key as presented in Appendix II.

2.1 Aggregation criteria and method

Aggregation of the European soils has been based on the following four criteria:

1 Soils within a soil category should show a similar behaviour with respect to soil degradation processes;

2 Differences between soil categories should be based on differences in the reaction to the soil degradation processes;

3 The soil categories must cover a large enough extent to be recognizable on the map;

4 The number of soil categories should be limited to 8 - 12 for presentation purposes.

The degradation processes considered are wind and water erosion, soil compaction, acidification and pollution of groundwater and ecosystem. These processes will be elaborated in Chapter 4.

To fulfil the first and second criteria eight soil characteristics influencing the vulnerability to degradation processes have been estimated for all relevant soil units. These characteristics are: (a) soil moisture regime, (b) slope class, (c) soil depth and stoniness, (d) the occurrence of salt, (e) the depth of the groundwater table, (f) topsoil texture, (g) topsoil organic matter content and (h) topsoil acidity. The third and fourth criteria strongly determined whether or not to use a potential soil category.

The eight soil characteristics all have their own relationships with the distinguished soil degradation processes.

- **Soil moisture regime:** The soil moisture regime gives an indication of the potential for plant growth. An aridic soil moisture regime hampers plant growth and increases the danger of erosion.
- **Slope class:** Especially in relation to water erosion the steepness of the slope is a major factor in determing the vulnerability.
- **Depth of solum to continuous hard rock and stoniness:** soil depth has implications for, amongst other aspects, soil erosion. Even a slight loss of soil might have repercussions for the present ecosystem (including agriculture and forestry) on shallow soils due to loss of water-storing capacity, fertility and even anchorage for the vegetation. For deep soils the effects are less in the short term. In addition, in areas with continuous hard rock at shallow depths, the precipitation surplus quickly reaches the surface waters.
- **The presence of salts:** High salt concentrations in the soil water strongly influence plant growth directly by disturbances in water- and nutrient uptake (osmotic effects, unfavourable ionic ratios, toxic effects) and, indirectly, by influencing physical soil characteristics (deterioration of aeration- and drainage capacity). This influence on vegetation (hampered growth) makes them more liable to soil erosion.
- **The presence of shallow groundwater:** groundwater and the presence of humus (organic matter) may give anaerobic soil conditions. In the case of nitrates the presence of shallow groundwater increases denitrification and thus the buffering capacity of the soil for nitrates (nitrates are transformed into elementary nitrogen and N_2O). For pesticides, shallow groundwater is, on the contrary, assumed to retard degradation of these substances and increase the threat of the drinking-water reservoirs.

- **Topsoil texture:** The texture of the soil is determined by the ratio of clay - silt and sand. The amount of clay particles strongly influences the binding capacity of the soil, especially for cationic substances, and therefore the buffer capacity. In addition clay particles increase the stability of soil agregates, and thereby the resistance to erosion and compaction.
- **Organic matter content:** organic matter plays an important role in the binding of substances, both organic and inorganic. On a weight basis, it outweighs the binding capacity of other soil constituents. In addition organic matter content influences agregate stability and thereby the resistance against erosion and compaction.
  A special case is soil consisting of alomst pure organic matter. Peat and muck soils (organic soils) originally have shallow to very shallow groundwater tables, occur on level topography and are mostly acid to very acid. Under natural vegetation or grassland, and without drainage, they are very stable. Depending on their reclamation they become more-or-less vulnerable to different type of soil degradation, e.g. wind erosion. They may be totally destroyed when they are dug for briquette, mould or moss-litter production, leaving larger water bodies or poor sandy soils.
- **Acidity:** soil acidity or proton activity, usually expressed as pH, influences the binding capacity of sesquioxides (iron, aluminum and manganese (hydr)oxides), and humus, and to a lesser extent, of clays. In addition, it influences the speciation of substances in solution and with it their tendency to bind to the soil matrix.

Not all the characteristics have been employed to their full extent, either because of the scale of the map or because the characteristic was not relevant. For example, the organic soils have not been further subdivided, although the FAO-Unesco legend (1974) offers the possibility to distinguish between acid and non-acid organic soils. Given the scale of the map it was decided that this was not useful. As can be seen in *Figure 1* the mineral soils are divided on the second level into shallow and deep soils. This division is not sensible for organic soils, let alone the scale problem, because organic soils are all deep (for definition see aggregation key, Appendix II). A comparable case is seen for the 'humus rich soils’. While the ’humus poor soils’ are subdivided on the basis of texture this is not useful for the humus rich soils (’Black earths’), because they are mainly loamy soils. The only exception of some importance are the Vitric Andosols in Iceland, which are sandy.

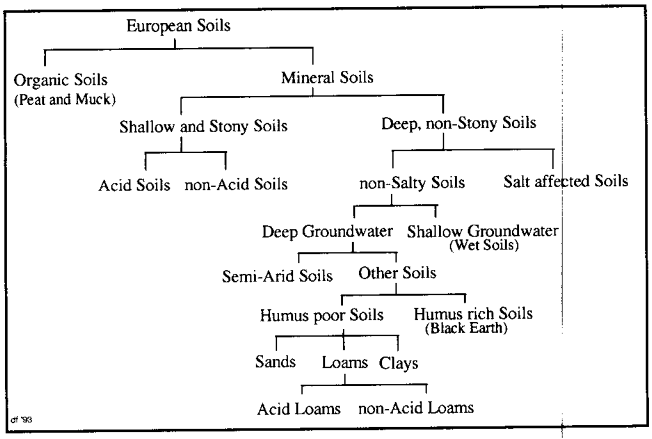

Figure 1 Aggregation of European soils.

The slope classes, provided on sheet V of the Soil Map of the World (FAO-Unesco, 1981 ’Europe’), have played a secondary role in aggregation. Slope class has been mainly used to estimate the vulnerability of a given category to soil degradation processes, notably to soil erosion.

The classification/aggregation steps shown in *Figure 1* will be discussed in §2.3, following the structure as presented in this figure.

2.2 Estimation methods of soil unit characteristics

Some of the eight soil characteristics can be directly obtained from the World Soil Map (FAO-Unesco, 1981); others have to be estimated on the basis of available information from reports and general soil textbooks. Although some soil characteristics can be directly obtained from the map, they cannot always be directly attributed to the soil units. Adjudication is hindered by the fact that some soil units are not homogeneous in respect to certain characteristics. This will be elaborated in the next section..

2.2.1 Soil characteristics obtained from the soil map

The soil characteristics which can be derived from sheet V of the World Soil Map (FAO-Unesco, 1981) are topsoil texture and slope class (both given for each map unit) and to some degree soil depth (lithic phase), stoniness (stony phase), salt influence (saline and sodic phase) and depth of the groundwater table (phreatic phase). Nevertheless some assumptions have to be made to translate map unit information to soil unit information, as will be explained below.

The number of soil units which compose the legend of the Soil Map of the World - Volume V Europe - is 78, of which 67 occur within the European territory; the number of map units is over 750. A map unit is not necessarily homogeneous - i.e. when it does not consist of just one soil unit, which is generally the case on a small-scale map, it is composed of a dominant soil and of associated soils, the latter covering at least 20% of the area. Important soils which cover less than 20% of the area are added as inclusions (FAO-Unesco, 1974).

The textural class of the dominant soil and the slope class are given for each association (map unit). Phases are subdivisions of soil units based on characteristics which are significant to the use of management of the land, but are not diagnostic for the separation of soil units themselves (FAO-Unesco, 1974). The phases recognized in Volume V of the World Soil Map are: stony, lithic, petrocalcic, petrogypsic, phreatic, with fragipan, saline and sodic (FAO-Unesco, 1981; for definitions see FAO-Unesco, 1974).

It has been decided - for reasons of simplicity - that soil categories with a similar vulnerability to degradation processes should be established by aggregation of soil units. This means an aggregation of dominant soil units, which in themselves consist of map units differing in composition for associated soils, relevant soils, soil phases, texture class and/or slope class. For each soil unit occurring as 'dominant soil' the texture class, slope class and soil phase with the largest extent have been assumed as representative for the soil unit. Some examples are given in Appendixes IV and V. Estimates of topsoil texture and slope class are given in Appendix III, as well as in sections of Chapter 3.

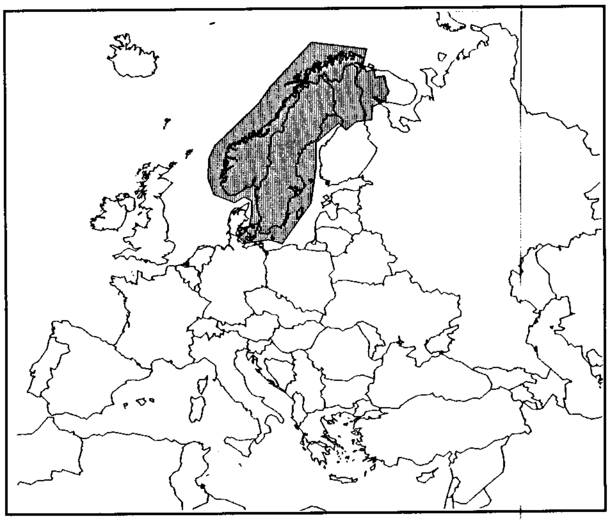

Figure 2 Selected area with different soil characteristics for Orthic Podzols and Eutric Cambisols.

For one soil unit, the Orthic Podzols, this procedure would have led to unacceptable consequences on the map. Orthic Podzol in Scandinavia are mainly stony, while in the other parts of Europe they are mainly non-stony. Thus assuming Orthic Podzols as either stony or non-stony would, in any case, lead to a very visible misclassification in one area on the generalized soil map. Because this stoniness of the Orthic Podzols is confined to Scandinavia, it has been possible, by means of GIS tools to use a classification deviating for this area. These soil units have been classified as acid, shallow and stony soils (§3.2.1). The units outside the selected area have been classified as sandy soils (§3.4.2). *Figure 2* shows the area which has a deviating aggregation of soil units. In addition to the Orthic Podzols, the Eutric Cambisols have been differentially classified as well for this area. Most Eutric Cambisol map units are characterized by either a stony or a lithic phase (see §3.2.2. and Appendix IV). In the selected area the Eutric Cambisols are nevertheless non-stony and are therefore classified as non-acid loamy soils (§3.4.4).

2.2.2 Soil characteristics derived from other sources

Unlike texture and slope, characteristics like, for example, organic matter content and acidity of the topsoil are not directly obtainable from sheet V of the World Soil Map (FAO-Unesco, 1981). The classification key of FAO-Unesco (1974) provide information to a certain degree on certain soil characteristics at soil unit level. Examples are soil depth (Lithosols), groundwater influence in the soil profile (Gleysols and Gleyic units), organic matter content (Histosols, presence of Histic, Mollic, Umbric or Ochric A-horizon), and acidity of the topsoil or specific subsoil horizons or layers (base saturation criteria ➡ Dystric versus Eutric units, for example; and presence of calcium carbonate ➡ Calcaric and Calcic units). But for many of the soil units the information is not explicitly derivable from the FAO-Unesco classification key (1974).

For each of the characteristics the estimation method will be explained; estimates are given in Appendix III.

Organic matter

The organic matter content of FAO-Unesco soil units in Europe have been estimated by Fraters et al. (1993), who at that time estimated the organic matter content, when relevant, of arable topsoils. Arable soils usually have lower organic matter content than grasslands and forest soils.

Soil acidity

The topsoil pH has been estimated by Fraters and Van Beurden (1993) for soil units occurring within the European Community. They distinguished three classes: class 1 soils with a pH_{salt}[1] lower than 5 (acid soils); class 2 soils with a pH of 5 - 6.5 (slightly acid soils) and class 3 soils with a pH higher than 6.5 (neutral to alkaline soils). The pH class

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[1] pH_{salt} is the pH determined in KCl or $CaCl_2$ solution, this pH is usually 0.5-1 unit lower than the pH_{H2O}.

has been estimated for the non-EC soil units using the classification method employed by Fraters and Van Beurden, based on information from the FAO-Unesco classification key (1974) and general soil science textbooks (FitzPatrick, 1991; Driessen and Dudal, 1989; Schachtschabel et al., 1989).

In general, the following Major Soil Groups are assumed to have acid topsoils: Acrisols, Ferralsols, Lithosols, Podzols and Podzoluvisols, of which the Ferralsols do not and the Acrisols do occur in Europe, but only to a limited extent; *Ferralsols* are developed in mainly acidic rocks (FAO-Unesco 1981, p.72). *Lithosols* are mainly acid to slightly acid, but neutral and alkaline soils also occur. Their depth is very limited and therefore their buffer capacity as well. *Podzols* are known to be acid soils (FAO-Unesco 1981, p.71-72) as a consequence of their high degree of leaching and their low CEC. The surface horizons are normally acid, with pH_{H2O} values between 3.5 and 4.5 (Driessen and Dudal 1989, p.265). Although these soils are limed when agriculturally used, pH_{KCl} is still below 5 even in areas with intensive agriculture, as in the Netherlands (De Vries, 1993). Increasing the pH above a pH_{salt} of 5.0-5.5 may result in micronutrient deficiencies, especially zinc, iron and manganese (Moraghan and Mascagni, 1991). According to Driessen and Dudal (1989), *Podzoluvisols* have moderately to strongly acid soil, with pH_{KCl} values from lower than 4 to 5.5 or slightly higher. FitzPatrick (1991) describes a generalized Gleyic Podzoluvisol profile: 'the pH values increase steadily from about 5.0 to 5.5 at the surface to 6.0 in the lowest horizon'. He does not state whether this is a pH_{salt} or pH_{H2O}. Sample profiles from FAO (1981, p.110-117) have the following pH in the upper horizons (covering at least 30 cm of topsoil): Dystric Podzoluvisol under forest (Belgium): pH_{KCl} 3.3-3.7, pH_{H2O} 3.6-4.7; Eutric Podsoluvisol under forest (Russia): pH_{KCl} 4.0-4.3, pH_{H2O} 4.9-5.6; and Gleyic Podzoluvisol under pasture (France): pH_{KCl} 4.8-5.0, pH_{H2O} 5.9-6.1. Sample profiles from Soil Taxonomy (Soil Survey Staff, 1975) have pH's in the upper horizons of: Gleyic Podzoluvisol under forest (pedon 11): pH_{H2O} 4.9-5.0, under abandoned pasture (pedon 45): pH_{H2O} 4.9-5.2.

The Rendzinas, Solonchaks and Solonetz are assumed to have neutral to alkaline topsoils. *Rendzinas* are formed in calcareous material and the upper horizon usually contains up to 80% calcium carbonate, with pH values above 8.0 (FitzPatrick 1991, p.260-261). According to Schachtschabel et al. (1989, p.410-411) the upper horizon is slightly alkaline to at most slightly acid. An sample profile from FAO-Unesco (1981, p.119) has a pH_{H2O} of 7.9-8.4 in the upper horizons (arable land, France). An example from Soil Taxonomy (Soil Survey Staff, 1975) has a pH_{H2O} in the upper horizons of 7.6-8.0 (pedon 88). Salt-affected soils (*Solonchacks* and *Solonetz*) are mostly neutral to strongly alkaline soils. FitzPatrick (1991) gives generalized profiles for both types; in the Solonchak profile the pH of the upper horizon varies from 8.3 to 8.5 (p.267), in the Solonetz profile from 6.8 to 8.1 (p.273). According to Schachtschabel et al. (1989, pp. 445-446) the pH of Solonchaks depends on the type of salt. Soda-rich soils are strongly alkaline (pH_{H2O} often above 9), chloride-rich soils are slightly alkaline and gypsum-rich soils are neutral (often below 7). An sample profile of a Solonetz from Rumania has a pH_{H2O} in the upper horizons of 7.5-8.5 (Schachtschabel et al., 1989, p.446). An Orthic Solonchak under arable use (Spain) has pH values in the upper horizons of 7.0-7.2 (KCl) and 8.3-8.6 (H_2O) (FAO-Unesco 1981, p.198-199). A Gleyic Solonchak under natural vegetation (France) has pH_{H2O} values of 7.0-7.8 (paste) and 7.4-8.7 (soil/water ratio of 1:2.5). Two Orthic Solonchaks from the US (Soil Survey Staff, 1975) have pH_{H2O} values of 8.4-8.6 (paste) and 9.0-9.8 (1:10) (pedon 41, natural grassland), and 8.4-8.5 (paste) and 9.0-9.1 (1:10) (pedon 61, natural very low density bush). Solonetz profiles from Soil Taxonomy (Soil Survey Staff, 1975) have pH_{H2O} values in the upper horizons of: Gleyic Solonetz 6.8-8.4 (paste) and 4.9-6.2 (1:1) (pedon 24, arable; pH_{KCl} 3.3-5.0), and 7.3-8.9 (paste) and 7.9-9.9 (pedon 100, low density brush); Mollic Solonetz 7.2-8.5 (paste) and 7.2-9.0 (1:5) (pedon 5, arable), 6.4-8.4 (1:1) (pedon 87, native grassland), 6.0-6.7 (1:1) and 6.4-7.5 (1:10) (pedon 95, native meadow); Orthic Solonetz 5.6-8.6 (1:1) and 6.2-9.4 (1:10) (pedon 23, natural grassland), 5.5-7.4 (1:1) and 6.0-8.0 (1:10) (pedon 54, native grassland), 8.7-9.9 (1:1) and 9.2-10.2 (1:10) (pedon 58, grassland).

For the other Major Soil Groups, it depends on the soil unit characteristics whether or not the soil is classified as acid, slightly acid or neutral to alkaline.

A) Topsoils of Dystric, Humic and Gelic units are assumed to be acid. *Dystric units* have horizons with a $pH_{H2O,\ 1:5}$ of less than 5.5 (Histosols) or a base saturation (by NH_4OAc) of less than 50% (other Major Soil Groups). *Humic units* usually either have an umbric A horizon or a dystric histic H horizon (both have a base saturation of less than 50%). If a soil horizon has a base saturation of less than 50% the pH_{salt} , if usually below 5.0 and never above 5.5 (non-published analysis of Gardiner profile data, 1987). Humic Andosols, for example, vary from moderately to strongly acid, with pH values as low as 4.5 on the surface (FitzPatrick 1989, pp.186-189). *Gelic units* occur within or just south of the permafrost zone. There are no specific data or references to these soil units. There are two reason why they are assumed to be acid: (1) they are within a zone of acid soils (Gleyic and Orthic Podzols and Dystric Histosols), and (2) they have acid-associated soils. Gelic Histosols have as associated soils Dystric Histosols, and Gelic Regosols have as associated soils Gelic Gleysols and Gelic Histosols. It is assumed that the difference is mainly the depth of the permafrost within the profile.

B) All the Calcic, Calcaric and Gypsic units are assumed to have neutral to alkaline topsoils. Calcareous material is present. Although the classification of the soil units is usually based on the characteristics of the B horizon, it is assumed that topsoil pH is more-or-less related to the pH of the subsoil horizon. In addition, estimating sensitivity of pollutants leaching to groundwater or sensitivity to acidification of the soil subsoil characteristics is important as well. It is known that, for example, topsoils of Calcic Chernozems have sometimes been decalcified and may have a pH as low as 5.5, but also may be as high as 8.0 (FitzPatrick, 1989 p.198).

C) All other soil units are assumed to have a slightly acid to neutral topsoil. This has been roughly checked with the available information. Three exceptions have been found. Haplic units of the Chernozems and of the Kastanozems probably have a neutral to alkaline topsoil, as well as the Luvic unit of the latter. Therefore these three units are assumed to have a neutral to alkaline topsoil. Kastanozems have pH values usually above neutrality, increasing from about 7.0 on the surface to over 8.0 in the carbonate accumulation (FitzPatrick, 1989, pp.230-234; Driessen and Dudal, 1989, pp.215-218). The upper horizons of an sample profile of a Luvic Kastanozem (FAO-Unesco, 1981, pp.142-143) have pH_{H2O} values of 7.1-7.4. The Chernozem surface soils are neutral in reaction (pH 6.5-7.5), but the pH may reach a value of 7.5-8.5 in the subsoil (Driessen and Dudal, 1989, p.224). Towards the northern fringe of the Chernozem belt the surface soil is slightly acid (pH 6.0-6.5) (Driessen and Dudal, 1989, p.222). The Luvic Chernozems are dominant in the northern fringe. Upper horizons from sample profiles (FAO-Unesco, 1981, pp.104-109) have pH_{H2O} values of 7.6 (Haplic Chernozem), 8.1-8.2 (Calcic Chernozem; pH_{KCl} 7.2), and 6.6-6.7 (Luvic Chernozem).

Haplic and Luvic Xerosols might have higher pH values as well. Because no data are available, the initial classification of slightly acid to neutral has not been changed.

2.3 Accounting for aggregation

The sixtyeight dominant soil units have been classified using the aggregation key given in Appendix II. This key is developed using the four criteria mentioned in §2.1. In this paragraph an account is given, following the structure presented in *Figure 1.*

Organic soils

The organic soils (peat and muck soils) are separated from the mineral soils because they consist mainly of organic materials, resulting in special characteristics and problems in relation to reclamation. The fact that these soils consist mainly of organic matter is due to excessive wetness of the soil, usually combined with low temperatures, which hamper degradations of the litter produced by the vegetation. As has been explained above, organic soils are not further subdivided.

Mineral soils

Mineral soils are divided into two groups on the basis of their soil depth. Soil depth has implications for, amongst other aspects, soil erosion. Even a slight loss of soil might have repercussions for the present ecosystem (including agriculture and forestry). In the FAO-Unesco legend (FAO-Unesco, 1974) the Lithosols (the Major Soil Group of soils limited in depth by continuous coherent and hard rock within 10 cm of the surface) and the lithic phase (as lithosols, but at 50 cm instead of 10 cm) refer to soil depths less than 50 cm. In addition, the petrocalcic, petrogypsic, petroferric and duripan phases refer to the occurrence of continuous cemented or indurated horizons within 100 cm of the surface of, respectively, calcium carbonates, gypsum, iron, and silica. In Europe the petrocalcic and petrogypsic phases occur to a limited extent only; the other two phases do not occur on the map (FAO-Unesco, 1981). Fragipans occur, to a limited extent, within 100 cm of the surface. This is a loamy subsurface horizon which has a high bulk density, is hard or very hard and seemingly cemented when dry. Except for the lithic and stony phases, the other phases have not been accounted for explicitly. On the European soil map the stony phase is very frequent. The stony phase marks areas where the presence of gravel, stones, boulders or rock outcrop in the surface layer or at the surface makes the use of mechanized agricultural equipment impracticable. Although the stony phase does not explicitly include a limited soil depth, soils with a stony phase are usually limited by depth as well and loss of fine material from the solum has many disadvantages.

The shallow and stony soils are subdivided on the basis of their acidity. Differences in texture are relatively small; i.e. between and within soil units, almost all different texture classes occur. Differences in organic matter content are small for the main soil units within this set; only the Andosols have a high organic matter content (Fraters et al., 1993), but they form less than 0.5% of the shallow and stony soils (see §3.1).

The presence or absence of salt influence in the solum has been used to split the other (not stony or shallow) mineral soils into salt-affected and non-salty soils. The semi-arid soils are excluded from the salt-affected soils, as will be explained in §3.2. Two types of salt-affected soils exist: the saline soils, which are characterized by a high salinity, and sodic soils, which are characterized by a relative high amount of sodium occupying the adsorption complex of the soil. For both types of salt-affected soils 'through' saline (Solonchaks) and sodic soils (Solonetz) as well as 'less affected' soils (saline and sodic phase) are taken into account. For the latter, it has been decided on the basis of area information whether or not a soil unit is assumed to have a saline and/or a sodic phase, as explained in §2.2.1.

On the generalized soil map saline and sodic soils are not separated. The 'through' salt-affected soils form a minority (1% of the land area, being 15% of the salt-affected soils). Distinguishing between saline and sodic phase soils is difficult, because for the Kastanozem soil units both saline and sodic phase map units occur. In addition, the extent of this soil category is too small to further subdivide.

The depth of the groundwater table has been used to distinguish between wet and non-wet soils in the group of soils not affected by salts which are 'deep' and non-stony. On the Soil Map of the World (FAO-Unesco, 1974,1981) the phreatic phase is shown, i.e. soils which have a groundwater table between 3 and 5 m, but none of the soil units on the European map (FAO-Unesco, 1981) is dominated by this phase. The soil units with hydromorphic properties in the solum are assumed to have shallow groundwater (< 200 cm below the surface). These are the soils with strong groundwater influence (Gleysols) and the soils of which only the lower horizons are influenced (Gleyic units). The soils developed from recent alluvial deposits are incorporated in this category as well, because they possess many of the properties of the hydromorphic soils (see §3.3.1). Large differences in topsoil texture and acidity exist; nevertheless, further division of this category is not carried out due to their limited extent.

The soils characterized by a semi-arid moisture regime are separated from the other soils without groundwater influence in the solum. This specific land characteristic determines to a large extent their vulnerability to a large extent, especially with reference to erosion. This category is not further subdivided for reasons of presentation

The remaining soil units are aggregated on the basis of organic matter content, texture and acidity. Formally, first the humus-rich soils (more than 6-7% organic matter) are separated from the other soils, then the humus-poor soils are subdivided according to texture (sands, loams and clays) and, finally, the loams are divided into acid and non-acid loams. But the resulting categories are in fact: (1) humus-rich, non-acid loamy soils, (2) humus-poor, acid sandy soils, (3) humus-poor, acid loamy soils, (4) humus-poor, non-acid loamy soils, and (5) humus-poor non-acid clayey soils (see §3.4).

Climate and slope have been considered in estimating the vulnerability of semi-arid soils and wet soils, respectively. Semi-arid soils occur in regions were vegetation will usually be scarce due to a long period of drought. In addition, rainfall is erratic and can be of a high intensity. Wet soils occur in a level to gently undulating landscape. Due to the shallow groundwater, vegetation will usually not suffer from drought. For both semi-arid soils and wet soils it is assumed that the factors mentioned will be of greater importance than texture in relation to vulnerability. Subdivision of these categories based on texture and/or acidity, for example, would lead to too many classes which would be hard to identify on the map.

3. Description of the general soil groups

Eleven soil categories have been distinguished. For the sake of a logical presentation the soil categories have been grouped on the basis of the most important characteristics: soil depth, climate and drainage conditions. The four sets of soil categories are:

(1) Shallow and stony soils
  - acid shallow and stony soils
  - non-acid shallow and stony soils

(2) Dry region soils
  - semi-arid soils
  - salt-affected and sodium rich soils

(3) Imperfectly drained soils
  - wet soils
  - peat and muck soils

(4) Well-drained soils
  - Black earths
  - sandy soils
  - acid loamy soils
  - non-acid loamy soils
  - clayey soils

In this chapter the general characteristic of the set will be discussed for each set of soil categories. On *Map 1* (see Appendix I) the occurence of the soil categories is shown. The significance of the map will be discussed in chapter 4. The characteristics of the soil categories within the set will be discussed in subsections. For each soil category a summary block is presented with information on the soil units which belong to the categories, the extent of the category on the map and the extent of the separate soil units. In addition, for each soil unit full name and FAO-Unesco symbol, the organic matter content, pH class and texture class of the topsoil are given, as well as the phase(s) occurring in over 20% of the map area.

The extent of the category is determined using Arc/Info frequency analysis tools. The range of the soil units is derived from FAO-Unesco data (1981, Table 3). General characteristic, like climate, topography and land use will be given for each soil category. These data come from FAO-Unesco (1981), unless indicated otherwise. The organic matter content (O.M.) is given as the percentage organic matter in the topsoil (Fraters et al., 1993). The pH is given as a pH class: class 1 soils with a pH_{salt}[1] of less than 5 (acid soils), class 2 soils with a pH of 5-6.5 (slightly acid soils) and class 3 soils with a pH more than 6.5 (neutral to alkaline soils); see section §2.2.2. Topsoil texture is given as well as classes. Three classes are used: class 1 are soil units with mainly coarse textured soils, class 2, soil units with mainly medium textured soils or with half coarse- to half fine- textured soil or with all three types of topsoil texture. Class 3 are soil units with mainly fine-textured soils; see §2.2.2 and Appendix V.

3.1 Shallow and stony soils

The shallow and stony soils (Set 1) cover about 30% of the land surface of Europe. They comprise the Lithosols (soils with continuous coherent and hard rock within 10 cm of the surface) and soil units with large areas mapped as 'lithic phase' (continuous and coherent hard rock within 50 cm) or 'stony phase' (the presence of gravel, stones, boulders or rock outcrops in the surface layers which makes the use of mechanized agricultural equipment impracticable)[2].

[1] pH_{salt} is the pH determined in KCl or $CaCl_2$ solution, this pH is usually 0.5-1 unit lower than the pH_{H2O}.

[2] The *petric, petrocalcic, petrogypsic, petroferric and duripan phases* all mark soils with an continuous cemented or indurated horizon within 100 cm of the surface (for definitions, see FAO-Unesco, 1974). Although some of these phases occur in Europe none of the soil units was

For all dominant soil units in this set, map units[1] occur which are neither lithic, nor stony. The topography is usually hilly to mountainous. Where the topography is level to rolling these soils are usually neither lithic nor stony. Their limited depth along with the steep topography make these soils susceptible to water erosion. Based on their pH two soil categories have been distinguished: acid and non-acid soils.

3.1.1 Acid-shallow and stony soils

The acid-shallow and stony soils occur extensively throughout Europe under climatic conditions ranging from cool marine to temperate Mediterranean to Taiga. The organic matter content of the topsoil is usually low (< 6%). Texture of the topsoil may range from coarse to fine. The units with the largest range are the Orthic Podzols, the Dystric Cambisols and the Lithosols.

Acid-shallow and stony soils Total area: 21%

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase[*2] (>20%)
Dystric Cambisols	Bd	5.7	3	1	2	stony
Humic Cambisols	Bh	0.9	5	1	2	stony
Lithosols	I	5.6	1	1	2	'lithic'
Orthic Podzols	Po[*3]	8.6	4	1	1	stony
Humic Andosols	Th	< 0.1	14	1	2	stony

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3)

[*2] For Lithosols the phase is placed in quotation marks because it is not shown on the map as the definition of Lithosols implies the requirements of the lithic phase.

[*3] Po units in northern Europe. For Po unit about 60% of this area is assumed to be stony.

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dominated by one or more of these phases.

[1] a dominant soil unit can occur on several places on the map. Map units with the same dominant soil unit may have different associated soil units and/or other characteristics like slope, stoniness etc.

The Orthic Podzols belong partly to this category and partly to the sandy soils (see §2.2 and §3.4.2). The map units in Scandinavia (excluding the units occurring in Denmark and southern Finland, see *Figure 2*, mostly stony, are shown on the map as acid-shallow soils. They are predominantly stony sandy soils marked by a rolling to hilly topography, and they are largely afforested. In the southern part of Norway and Sweden some livestock farming, including dairying, is carried out.

The Dystric Cambisols occur extensively throughout Europe. They are largely associated with hilly to mountainous topography and are coarse to medium textured. About 40% of the map area is stony and 13% is lithic. These areas are mainly devoted to rough grazing and to forestry. A large area is neither lithic nor stony. This type of area is confined to the United Kindom and Ireland, western France, middle and southern Italy, and former Yugoslavia[1]. These units are largely devoted to livestock production and arable crops.

The Lithosols (soils with continuous coherent and hard rock within 10 cm of the surface) occur as complexes in the major mountain land masses of Europe, with as associated soils, Luvisols, Rendzinas, Podzols, Regosols and Rankers. Climatic types range from continental Mediterranean to Taiga. Although the soils are mostly acid to slightly acid, neutral to alkaline units occur as well (soils formed on carbonate rock). Lithosols are mainly used for forestry and rough grazing.

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[1] The present map can be improved by selecting these areas and reclassifying the units to either sandy or acid loamy soils using GIS tools (see §2.2, Scandinavia).

3.1.2 Non-acid shallow and stony soils

The non-acid shallow and stony soils occur predominantly in south-western and middle Europe. The organic matter content of the topsoil is usually low (< 6%). Texture of the topsoil may range from coarse to fine. The soil units with the largest range are the Eutric Cambisols, the Calcic Cambisols and the Rendzinas.

Non-acid shallow and stony soils **Total area: 9%**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Eutric Cambisols[*2]	Be	4.2	3	2	2	stony
Calcic Cambisols	Bk	2.4	3	3	2	stony
Rendzinas	E	1.9	5	3	2	lithic/stony
Mollic Andosols	Tm	0.1	14	2	2	lithic
Rankers	U	0.3	3	2	2	stony
Ferric Luvisols	Lf	< 0.1	2	2	3	stony

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

[*2] Be units in non-Scandinavian area, see text. For Be units about 90% of this area is assumed to be stony.

The Eutric Cambisol map units belong partly to this group and partly to the loamy soils (see §2.2 and §3.4.4). The non-Scandinavian units are mostly stony or lithic, but about 48% of the map area occupied by Be units is neither lithic, nor stony. This is usually the case in areas with a level to rolling topography, e.g. western and southern France, the U.K. and Ireland and north-eastern Italy. The topsoil has a loamy and sometimes clayey texture, a pH between 5.5 and 7 and contains about 3% organic matter. Soils are used for arable crops, vines and fruit production, as well as livestock production.

The Calcic Cambisols are largely confined to Spain and Italy, where they occur under Mediterranean climatic conditions. They are associated with hilly and mountainous topography and are mostly stony (83% of the map area). The topsoil is loamy or clayey, has a pH > 7 and contains about 3% organic matter. Calcic Cambisols are devoted to cereals, fruits, vines, rough grazing and forestry.

The Rendzinas occur under a broad climatic range. They are developed in calcareous material, and carbonate rock usually occurs within 50-80 cm of the surface. Topsoils are loamy to clayey, pH is > 7 and the organic matter content about 5%. Where topography is not limiting they are highly important arable soils. In the mountains grazing and forestry are dominant.

3.2 Dry region soils

The dry region soils (Set 2) cover about 9% of the European land surface. They occur under Mediterranean, semi-arid or arid climatic conditions. These soils are subjected to severe moisture deficits. They have a level to rolling topography, nevertheless, they are highly susceptible to erosion and the desertification hazard is high. This set contains two soil categories: (1) the semi-arid soils and (2) the salt-affected and sodium-rich soils.

3.2.1 Semi-arid soils

The semi-arid soils occur mainly in south-eastern Europe around the Caspian Sea. They are often susceptible to either salinization or alkalization (solonization) and a part of the map units has either a sodic or saline phase (for definition: FAO-Unesco, 1974). The predominant soil units are the Haplic and Luvic Xerosols. A large area of shifting sands, just north of the Caspian Sea, is included in this category.

Semi-arid soils **Total area: 2%**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (20%)
Dunes	D	0.7	< 1	2	1	
Haplic Xerosols	Xh	0.5	1	2	2	
Calcic Xerosols	Xk	0.2	1	3	3	
Luvic Xerosols	Xl	0.5	1	2	2	sodic
Gypsic Xerosols	Xy	< 0.1	1	3	3	saline

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

Haplic and Luvic Xerosols have a sandy to silty topsoil texture. The pH of the topsoil is usually > 7 and the organic matter content is very low (≤ 1%). The Haplic units are devoted to arid grazing and some arable cropping. They are sometimes saline. The Luvic Xerosols are used for arable cropping and some forestry. A sodic phase occurs.

3.2.2 Salt-affected and sodium-rich soils

Two types of soils are recognized: saline or salt-affected soils and alkali or sodium-rich soils. The saline soils are characterized by a high salt content in the topsoil, which may severely hamper plant growth. In alkali soils the presence of sodium salts determines the soil properties; either the high alkalinity of the soil solution hinders plant growth, or the alkalinity renders the physical soil properties disadvantageous for supplying water to plants. Topsoils have a low to very low organic matter content (1-5%), are neutral to alkaline and usually have a medium to fine texture. Land use includes arable cropping, forestry and livestock production. Often more crops per year are possible under irrigation. This soil category contains truly saline and sodic soils (Solonchaks and Solonetz, respectively) and soils with a dominant saline and/or sodic phase (Kastanozems, Calcic Chernozems and Calceric Phaeozems). The Haplic Kastanozems are the soils with the largest range; together with Luvic Kastanozems and Orthic Solonetz they cover over 80% of the map area of this category.

Salt-affected and sodium rich soils Total area: 7 %

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase[*2] (>20%)
Calcic Chernozems	Ck	0.7	8	3	2	phreatic/saline
Calcaric Phaeozems	Hc	0.3	5	3	2	sodic/saline
Haplic Kastanozems	Kh	3.8	5	3	2	sodic
Calcic Kastanozems	Kk	0.4	3	3	2	sodic
Luvic Kastanozems	Kl	0.6	3	3	2	sodic
Gleyic Solonetz	Sg	< 0.1	3	3	3	'sodic'
Mollic Solonetz	Sm	< 0.1	4	3	3	'sodic'
Orthic Solonetz	So	0.7	2	3	3	'sodic'
Gleyic Solonchaks	Zg	0.2	3	3	3	'saline'
Orthic Solonchaks	Zo	< 0.1	1	3	3	'saline'

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

[*2] For Solonetz and Solonchaks units phase is placed in quotation marks, because it is not shown on the map as the definition of the units implies the requirements of either sodic or saline phase.

Haplic Kastanozems are formed in loess, have a near neutral pH and an organic matter content around 5%. They occur in south-eastern Europe and form a belt between the Chernozems ('Black earths') situated north of the Kastanozems and the other dry region soils (Xerosols and Orthic Solonetz) more to the south. Agriculture has to deal with dryness, which is the limiting factor. The principal crop is wheat; open pasture subsists in the sodic steppe.

Luvic Kastanozems and Orthic Solonetz occur south of the Haplic Kastanozems. The texture of the Solonetz is loamy to clayey and that of the Luvic Kastanozems loamy. The pH is higher than 7 and in the Solonetz profile pH's higher than 8 occur. The organic matter content of the topsoil is low to very low (2-3%). The soil and the arid climate permit little more than non-intensive open pasture.

3.3 Imperfectly drained soils

Imperfectly drained soils (Set 3) cover about 17% of the land surface, occur in all climates and are widely distributed. They are characterized by their level topography and either waterlogging at a shallow depth (for some part of the year or the whole year) or periodic flooding. Groundwater usually occurs within 200 cm of the surface. Two categories have been distinguished on the basis of presence or absence of a horizon of 40 cm or more consisting of organic material within the upper 80 cm (Histic H, for definition see FAO-Unesco, 1974). The wet soils (§4.3.1) do not have such a horizon, while the peat and muck soils (§4.3.2) do.

3.3.1 Wet soils

Wet soils usually occur on level up to gently rolling topography. The organic matter content of the mineral topsoil is usually low (< 6%) and the pH ranges from acid to neutral. All texture classes occur. Soil wetness is the major limitation for soils with waterlogging at very shallow depth; these soils are mainly used for livestock production. A large area of wet soils occurs just south of the permafrost zone in northern Russia. Forests are intensive and reindeer farming common. The soils without waterlogging are highly important agricultural soils. The intensive use of heavy agricultural equipment, agricultural chemicals and irrigation water may lead to chemical and/or physical soil degradation.

The soil units with the largest range are the Gleyic Podzols, Gleyic Luvisols, and Eutric and Calcaric Fluvisols.

Gleyic Podzols are confined to the Taiga zone in northern Russia. Forest are extensive and reindeer farming is common. Gleyic Luvisols occur all over the Luvisol belt. A large area of Gleyic Luvisols occurs in the upstream basin of the Dnjerp. They are used for arable

Wet soils **Total area: 14 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Gleyic Cambisols	Bg	0.4	3	2	2	
Gleyic Podzoluvisols	Dg	0.2	8	1	1	
Dystric Gleysols	Gd	0.2	5	1	3	
Eutric Gleysols	Ge	0.6	4	2	3	
Humic Gleysols	Gh	0.2	10	1	2	
Mollic Gleysols	Gm	0.8	4	2	3	
Gleyic Phaeozems	Hg	0.1	5	2	3	
Calcaric Fluvisols	Jc	1.1	5	3	2	
Dystric Fluvisols	Jd	< 0.1	5	1	2	
Eutric Fluvisols	Je	2.7	5	2	3	
Gleyic Luvisols	Lg	3.6	3	2	2	
Gleyic Podzols	Pg	3.4	4	1	2	
Placic Podzols	Pp	0.3	10	1	1	

[*1] provisional, estimates based on FAO-Unesco (1981, Table 3).

crops, livestock production and in some areas they are afforested.

The Calcaric and Eutric Fluvisols are distributed widely throughout Europe. They are highly important agricultural soils. In southern Europe irrigation is required for maximum yields. In some areas (e.g. Rhone Valley in France) vines, market gardens, fruits and orchards are concentrated on these soils. In the Netherlands and Belgium these soils are used also for grassland farming, intensively managed, in addition to arable farming.

3.3.2 Organic soils

Organic soils or 'peat and muck' are largely confined to cool and cold temperate climates and occur on a level topography. These soils have a thick soil horizon that is rich in organic material (more than 30% organic matter). In cold climates their agricultural potential is low and they remain under their natural vegetation cover. Under more favourable climatic conditions, their agricultural potential is usually limited by waterlogging, poor nutrient status and low bearing capacity. Under these conditions they are used for livestock production. In the Netherlands, Germany and Poland organic soils occur which are devoted to intensive arable and pasture use. Drainage of these soils may lead to their detoration due to consolidation and mineralization. After drainage these soils are susceptible to wind erosion. Large areas have been lost due to cutting peat for briquettes and peat mould.

Peat and muck soils **Total area: 3 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Dystric Histosols	Od	2.1	30	1	nr	
Eutric Histosols	Oe	0.1	30	2	nr	
Gelic Histisols	Ox	0.8	30	1	nr	

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

nr Not relevant, for organic soils the texture of the 'ash' is not determined.

3.4 Well-drained soils

The well-drained soils (Set 4) cover about 44% of the European land surface. They occur all over Europe, but are particularly extensive in eastern Europe. The well-drained soils are mostly deep, not affected by salt or groundwater and do not have a semi-arid moisture regime. This set contains five categories: (1) black earths, (2) sandy soils, (3) acid loamy soils, (4) non-acid loamy soils and (5) clayey soils.

3.4.1 'Black earths'

'Black earths' or the humus-rich well-drained soils, which occur on a level to hilly topography, extend from Rumania, Bulgaria and Hungary to the Ural mountains. The 'black earths' are highly important agricultural soils. These soils are not limited by depth, are not salt-affected and groundwater will be well below 200 cm of the surface. Topsoils contain more than 6% organic matter and have mainly a medium texture. Topsoils are mostly neutral to alkaline. The chemical and physical properties of these soils are very favourable. Summer drought and short growing periods limit their production potential. Land use comprises arable cropping and grazing. They are moderately susceptible to wind and water erosion.

'Black earths' **Total area: 9 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Haplic Chernozems	Ch	5.2	14	3	2	
Luvic Chernozems	Cl	3.5	8	2	2	
Orthic Andosols	To	< 0.1	8	2	3	
Vitric Andosols	Tv	0.2	8	2	1	

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

The Haplic and Luvic Chernozems are the soil units with the largest range. In addition to arable farming and grazing these soils are used for market garding and fruit in, for example, the Vienna basin in Austria and extend into former Czechoslovakia.

3.4.2 Sandy soils

Sandy soils are soils not limited by depth, are not salt-affected and groundwater will be well below 200 cm of the surface. Topsoils contain less than 6% organic matter, and their texture is coarse. They are mainly acidic. Sandy soils which occur under Taiga conditions are largely devoted to forestry and reindeer grazing. In western and middle Europe the sandy soils occur under other climate conditions; if the topography is level to hilly arable cropping is practised and sometimes vines and olives are grown. These soils are vulnerable to chemical deterioration due to their low buffering capacity.

Sandy soils **Total area: 9 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Humic Podzols	Ph	0.6	4	1	1	
Leptic Podzols	Pl	1.2	4	1	1	
Orthic Podzols[*2]	Po	5.7	4	1	1	
Cambic Arenosols	Qc	0.2	1	2	1	
Luvic Arenosols	Ql	< 0.1	1	2	1	
Gelic Regosols	Rx	1.3	10	1	1	
Dystric Planosols	Wd	0.1	1	1	1	

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

[*2] Except for Po units in nothern Europe. For Po units about 40 % of the area is assumed to be neither stony nor lithic.

The soil unit with the largest extent is the Orthic Podzol. These soils are largely confined to northern Europe. In part they are stony and belong to the acid-shallow and stony soils (see §2.2 and §3.1.1). In the alpine zone of Switzerland, Italy and Austria they are

afforested or used for alpine grazing. In valley areas some arable cropping is practised. In Denmark, Germany, England and Poland these soils are used for arable farming and grassland as well as forestry.
The Leptic and Humic Podzols occur under cool to cold temperate climates and occur mostly on a level topography. They are devoted to (for Humic Podzols intensive) arable farming and livestock production, and also afforestation in the more hilly regions. The Gelic Regosols occur extensively in the permafrost Taiga zone of northern Russia. Some reindeer grazing is practised.

3.4.3 Acid loamy soils

Acid loamy soils are not limited by depth, are not salt-affected and groundwater will be well below 200 cm of the surface. Topsoils contain less than 6% organic matter and have a medium texture. Topsoils are acid to slightly acid. These soils occur mostly on a level to rolling topography under cool to cold temperate and cold continental climate conditions, but they also occur under warm and cold marine, and Mediterranean conditions. Under less favourable climatic conditions these soils are mainly afforested or used for livestock production. Under more favourable climatic conditions they are highly important agricultural soils. They have a somewhat higher buffering capacity but are still vulnerable to chemical deterioration.

Acid loamy soils **Total area: 15 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Orthic Acrisols	Ao	< 0.1	2	1	2	
Dystric Podzoluvisols	Dd	3.3	2	1	2	
Eutric Podzoluvisols	De	12.1	3	1	2	

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

The Eutric and Dystric Podzoluvisols are the soil units with the largest range. The Dystric Podzoluvisols occur extensively in the central Taiga zone of northern Russia. Forest is the dominant land use. Some reindeer and cattle farming occurs, but because of climatic constrains, the cultivated area on these soils is small. The Eutric Podzoluvisols occur south of the Dystric Podzoluvisol belt and largely under cold continental conditions on a level topography. In the western part the Eutric Podzoluvisols are devoted mainly to livestock farming, with arable farming playing a minor role. In the eastern part coniferous forest is the main use of these soils.

3.4.4 Non-acid loamy soils

Non-acid loamy soils are not limited by depth, are not salt-affected and groundwater will be well below 200 cm of the surface. Topsoils contain less than 6% organic matter and have a medium texture. Topsoils are mainly slightly acid to neutral. The Orthic Luvisol is the soil unit with the largest range

Orthic Luvisols occur throughout Europe, except for northern Europe. They are highly important agricultural soils. Topsoils of this unit are low to very low in organic matter, slightly acid to neutral and the parent material is to a large extent loess, which is very vulnerable to erosion. They occur mainly on undulating and rolling terrain, but to a limited extent also on level, and hilly and mountainous topography. The latter Orthic Luvisol map

Non-acid loamy soils **Total area: 8 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Eutric Cambisols[*2]	Be	0.5	3	2	2	
Haplic Phaeozems	Hh	0.2	5	2	2	
Luvi Phaeozems	Hl	0.2	5	2	2	phreatic
Orthic Luvisols	Lo	6.2	2	2	2	
Vertic Luvisols	Lv	0.1	2	2	2	
Orthic Greyzems	Mo	0.6	4	2	2	
Eutric Planosols	We	< 0.1	1	2	2	fragipan

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

[*2] Be units in Scandinavia (see §2.2). For Be units about 10% of the area is assumed to be not stony.

units are stony or lithic and largely afforested. The other Orthic Luvisols are mainly used for arable and livestock farming, but in some areas they are devoted to vines or fruit production as well.

3.4.5 Clayey soils

Clayey soils are mainly confined to south-western Europe (France-Spain-Italy-Greece-Bulgaria), but also occur in southern Sweden and Finland, where they are particularly interesting for agriculture in these countries where acid-stony and acid-sandy soils with conifers. The clayey soils are not limited by depth, are not salt-affected and groundwater will be well below 200 cm of the surface. Topsoils contain less than 6% organic matter and have a fine texture. Topsoils are mostly slightly acid to alkaline. The soils occur on a rolling to mountainous topography and are often stony or petrocalcic. They should be presented on the map as non-acid shallow and stony soils, but due to their spottiness they could not be separated from the non-stony map units (as was done for the Orthic Podzols). Their topography makes them susceptible to erosion. Soil units on a level to rolling topography are devoted to arable cropping and dairy farming. The clayey soils are used for arable crops, including vines, livestock production and forestry. They have a higher buffering capacity for chemical inputs due to their finer texture and higher base saturation. The soil unit with the largest range is the Chromic Luvisol[1].

Clayey soils **Total area: 4 %**

Soil unit	Symbol	Area[*1] (%)	O.M. (%)	pH class	Texture class	Phase (>20%)
Chromic Cambisols	Bc	0.4	2	2	3	
Vertic Cambisols	Bv	0.5	3	2	3	
Chromic Luvisols	Lc	1.6	2	2	3	stony
Calcaric Regosols	Rc	0.3	1	3	3	stony
Eutric Regosols	Re	0.3	1	2	3	
Chromic Vertisols	Vc	< 0.1	2	2	3	
Pellic Vertisols	Vp	0.3	2	2	3	

[*1] Provisional, estimates based on FAO-Unesco (1981, Table 3).

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[1] A recent check of the data showed that a large part of the Chromic Luvisol map area is stony (62%); see Appendix IV. Notably the map units in Greece and Italy are stony. Therefore this soil unit should instead be included in the non-acid shallow and stony soils. As stated in the introduction with the current GIS tools these kinds of problems can be easily overcome.

4 Vulnerability of European soils

The soils in Europe do not all respond similarly to soil degradation processes. Whether degradation of soil occurs or not and to what extent depends mainly on the eight soil characteristics identified in §2.1. On *Map 1* (see Appendix I) the soil categories are shown which are discussed in chapter three.

Map 1 is not a vulnerability map; it is a generalized soil map. Vulnerability has to be specified with respect to agents, causes and effects (Desaules, 1991). Nevertheless the soils belonging to the same soil category do, in many respects, behave in a similar way to soil degradation processes and this map can help us get an idea of the areas in Europe vulnerable to the different types of soil degradation in general terms. It underlines the need of the research carried out in the framework of the SOVEUR project (e.g. Batjes and Bridges, 1991).

The map is intended to identify and highlight the major problem areas in Europe. It should not be taken as giving a detailed assessment of the situation on the local or subregional scale. The map should be evaluated primarily on a European scale.

Table 1 gives the vulnerability of the different soil categories for degradation. The vulnerability is given in respect to soil characteristics assuming that there are no differences in land characteristics, unless explicitly stated. Land comprises the total physical environment, including climate, relief, soils, hydrology and vegetation. All these characteristic determine whether or not degradation occurs. For example, loamy soils, both the acid and non-acid, are highly vulnerable to erosion compared with clays when the steepness of the slope, intensity and duration of rainfall, vegetation cover, etc. are the same. However, a bare clayey soil on a steep sloop in an area with an erratic heavy rainfall will be much more prone to water erosion than a forested loamy soil in a level landscape with a regular light rainfall.

Table 1 *Vulnerability of European soils to soil degradation.*

Soil Type	Degradation Type Area (%)	Erosion	Compaction	Acidification	Pollution
Acid Shallow	21	■■■		■■■	■■■
Non-Acid Shallow	9	■■■			■
Semi-Arid	2	■■■			
Salt Affected	7	■■			
Wet	14		■■	■	■■■
Peat and Muck	3	Depends on land use and/or reclamation type			
Black Earths	9	■			
Sands	9	■■	■■■	■■■	■■■
Acid Loams	15	■■■	■■■	■■■	■■■
Non-Acid Loams	8	■■■	■■■	■■	■■
Clays	4	■	■■	■	■

☐ negligible ■ slight ■■ moderate ■■■ high

From *Table 1* it can be derived that sandy soils are much more vulnerable to soil pollution than 'black earths'. Black earths are neutral to alkaline, humus-rich loamy soils. Pesticides are adsorbed by the organic matter and degradation is usually fast in the fertile topsoil. Heavy metals are adsorbed strongly by the soil, which prevents their uptake by plants or soil fauna. The sandy soils have mostly acid humus-poor topsoils which hardly adsorb pesticides and heavy metals. They will be available for uptake by soil fauna and flora, and for leaching from the topsoil. In these soils heavy metals and pesticides threaten the groundwater as well as the soil flora and fauna. Loamy and clayey soils have an intermediate position between the sandy soils and the black earths. The increase in adsorption capacity from sandy to clayey soils, due to the increase in clay content often accompanied by increasing organic matter content, means increasing buffer capacity and decreasing vulnerability. However, soils with a relatively high concentration of heavy metals may become a potential threat when soil characteristics are changed, e.g. by soil acidification. In this case the buffer capacity of the soil decreases and heavy metals may be released.

For erosion both wind and water erosion are included in the estimation of the vulnerability. Important soil characteristics for vulnerability for erosion are depth of the solum to continuous hard rock, the presence of shallow groundwater, soil moisture regime, humus content and clay content. Shallow and stony soils are readily degraded when soil loss due to erosion occurs, because they do not have much fertile fine material and are therefore classified as highly vulnerable. Semi-arid soil are highly vulnerable due to climatic conditions (see above). Salt-affected soils are assumed to be less vulnerable to erosion than semi-arid soils because they usually occur on a level topography and water; thus vegetation is less scarce. The majority of the salt-affected soils are not 'true' saline or sodic soils, and therefore the decline of plant growth due to salinity effects is assumed to be less then the decline of plant growth due to water shortage by semi-arid soils. Wet soils are assumed either not, or only very slightly, vulnerable to erosion because of topography and the presence of shallow groundwater. Acid and non-acid loams are highly vulnerable due to their parent material (loess which is a product of wind erosion) and their lack of clay and organic matter. Sandy soils are assumed to be less vulnerable because of particle size. Although clay particles are finer than loess (silt), they usually form stable aggregates of a larger size than sand grains and are therefore less vulnerable to erosion. In addition, clay soil usually occurs on a level topography. The parent material of Black Earths is loess. Nevertheless these soils are assumed to be only slightly vulnerable to erosion because of their high organic matter content. Organic matter, like clay particles, improves the formation of stable soil aggregates, thereby diminishing the vulnerability to erosion.

For compaction both topsoil and subsoil are considered (Van der Pouw, pers. comm.). Subsoil compaction is considered to be more harmful than topsoil compaction. Topsoil compaction can be restored by normal ploughing. The shallow (and stony) soils, the semi-arid soils, salt-affected soils and Black Earths are not or very slightly vulnerable for compaction. Only the acid-shallow and stony soils are assumed to be moderately vulnerable and the Black Earths slightly vulnerable for topsoil compaction. Wet soils and humus- poor clay soils are assumed to be moderately vulnerable to compaction. Wet soils are moderately vulnerable, while humus-poor clay soils are not, to very slightly vulnerable, to subsoil compaction. Both soil categories are highly vulnerable to topsoil compaction. Sandy and loamy (both acid and non-acid) soils are highly vulnerable to subsoil compaction. Loamy soils are also slightly vulnerable to topsoil compaction.

The vulnerability to acidification is largely determined by the potential capacity of the soil to buffer acids. The parent material of the soil and the soil formation determine the buffer capacity. Vulnerability to pollution of groundwater and ecosystem is mainly determined by

(1) the capacity of the soil to bind pollutants and thereby hamper uptake by vegetation, and leaching to groundwater and or surface waters and (2) the capacity of the soil to transform pollutants in non-toxic and otherwise detoriating substances. Therefore the higher the clay and/or organic matter content the lower the vulnerability to pollution (see above).

It is not possible to give a generalized vulnerability classification for peat and muck. As has been stated in section 2.3 these soils are very stable under natural vegetation or grassland and without drainage. Their vulnerability strongly depends on land use and reclamation type. They may be totally destroyed when they are dug for briquette, mould or moss-litter production, leaving larger water bodies or poor sandy soils.

If we assume that the four degradation processes considered are all more-or-less equally harmful we can state that 15% of the area in Europe is extremely vulnerable (highly vulnerable to all processes) and that another 30% is very vulnerable (highly vulnerable to 3 out of 4 processes). Only 34% of the area is slightly vulnerable (for none of the processes highly vulnerable), including 7% of soils hampered by salinization or sodification (salt-affected soils).

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Appendix I Generalized soil map of Europe

Appendix II Aggregation key to the soil categories

1a. Soils belonging to the Histosols: Peat and muck soils (*Category 6*)
1b. Other soils: see 2.

2a. Soils with continuous hard rock within 50 cm of the surface (Lithosols and soils with lithic phase) or soils where the presence of gravel, stones, boulders or rock outcrops in the surface layers or at the surface makes use of mechanized agricultural equipment impractical (stony phase soils): see 3.
2b. Other soils: see 4.

3a. Acid soils (pH_{KCl} less then 5-6): Acid-shallow or stony soils (*Category 1*)
3b. Neutral to alkaline soils (pH_{KCl} more then 5-6): non-acid shallow or stony soils (*Category 2*)

4a. Soils affected by salts (Solonchaks and saline-phase soils) or soils rich in sodium (Solonetz and sodic-phase soils); if only a saline or sodic phase is dominant then the soil moisture regime should not be semi-arid: Salt-affected and sodium-rich soils (*Category 4*).
4b. Other soils: see 5.

5a. Soils with groundwater within 200 cm of the surface: Wet soils (*Category 5*)
5b. Other soils: see 6.

6a. Soils with a semi-arid soil temperature regime: Semi arid soils (*Category 3*)
6b. Other soils: see 7.

7a. Soils with an organic matter content of the (thick) topsoil of more than 6-7%: Black earth soils (*Category 7*)
7b. Other soils: see 8.

8a. Soils with a coarse or coarse/medium texture class: Sandy soils (*Category 8*)
8b. Soils with a medium, coarse/fine, or coarse/medium/fine texture class: Loamy soils, see 9.
8c. Soils with a medium/fine or fine texture class: Clayey soils (*Category 11*)

9a. Acid soils (pH_{KCl} less than 5-6): Acid loamy soils (*Category 9*)
9b. Neutral to alkaline soils (pH_{KCl} more than 5-6): Non-acid loamy soils (*Category 10*)

Appendix III Estimates of soil characteristics of the FAO-Unesco soil units

Soil unit name = full name according to FAO-Unesco legend (1974)
Symbol = Symbol used to indicate soil unit
O.M. = Organic matter content of topsoil when under agricultural use (Fraters et al., 1993).
pH class = 1: acid soils, 2: slightly acid to neutral soils, 3: neutral to alkaline soils (see text §2.2).
phase = important phase (for definitions see FAO-Unesco, 1974). Detailed information in Appendix IV. If phases are placed in quotation marks they are not shown on the map because phases are included in the definition of this soil unit.
texture class = 1: coarse-textured soils, 2: medium-textured soils or mixed-coarse and fine-textured soils, 3: fine-textured soils, nr: not relevant. For detailed information, see Appendix V.
slope class = main slope class, a: level to gently undulating, b: rolling to hilly, c: steeply dissected to mountainous; roughly estimated based on FAO-Unesco (1981, Table 3). Indicative only, not thoroughly checked.

Soil unit name	Symbol	Area (%)	O.M. (%)	pH class	Texture class	Phase (>20%)	Slope
Orthic Acrisols	Ao	< 0.1	2	1	2	non	a
Humic Andosols	Th	< 0.1	14	1	2	stony	bc
Mollic Andosols	Tm	0.1	14	2	2	lithic	bc
Orthic Andosols	To	< 0.1	8	2	3	none	c
Vitric Andosols	Tv	0.2	8	2	1	none	ab
Cambic Arenosols	Qc	0.2	1	2	1	none	a
Luvic Arenosols	Ql	< 0.1	1	2	1	none	ab
Chromic Cambisols	Bc	0.4	2	2	3	none	ab/bc
Dystric Cambisols	Bd	5.7	3	1	2	stony	bc

Soil unit name	Symbol	Area (%)	O.M. (%)	pH class	Texture class	Phase (>20%)	Slope
Eutric Cambisols	Be	4.7	3	2	2	stony	abc
Gleyic Cambisols	Bg	0.4	3	2	2	none	a
Humic Cambisols	Bh	0.9	5	1	2	stony	bc
Calcic Cambisols	Bk	2.4	3	3	2	stony	bc
Vertic Cambisols	Bv	0.5	3	2	3	none	a
Haplic Chernozems	Ch	5.2	14	3	2	none	a
Calcic Chernozems	Ck	0.7	8	3	2	phreatic/saline	ab
Luvic Chernozems	Cl	3.5	8	2	2	none	ab
Dunes	D	0.7	< 1	2	1	none	-
Calcaric Fluvisols	Jc	1.1	5	3	2	none	a
Dystric Fluvisols	Jd	< 0.1	5	1	2	none	a
Eutric Fluvisols	Je	2.7	5	2	3	none	a
Dystric Gleysols	Gd	0.2	5	1	3	none	b
Eutric Gleysols	Ge	0.6	4	2	3	none	a
Humic Gleysols	Gh	0.2	10	1	2	none	b
Mollic Gleysols	Gm	0.8	4	2	3	none	a
Orthic Greyzems	Mo	0.6	4	2	2	none	ab
Dystric Histosols	Od	2.1	30	1	nr	none	a
Eutric Histosols	Oe	0.1	30	2	nr	none	a
Gelic Histosols	Ox	0.8	30	1	nr	none	a
Haplic Kastanozems	Kh	3.8	5	3	2	sodic	a

Soil unit name	Symbol	Area (%)	O.M. (%)	pH class	Texture class	Phase (>20%)	Slope
Calcic Kastanozems	Kk	0.4	3	3	2	sodic	a/b
Luvic Kastanozems	Kl	0.6	3	3	2	sodic	a
Lithosols	I	5.6	1	1	2	'lithic'	b/c
Chromic Luvisols	Lc	1.6	2	2	3	stony	bc
Ferric Luvisols	Lf	< 0.1	2	2	3	stony	bc
Gleyic Luvisols	Lg	3.6	3	2	2	none	ab
Orthic Luvisols	Lo	6.2	2	2	2	none	ab
Vertic Luvisols	Lv	0.1	2	2	2	none	ab
Calcaric Phaeozems	Hc	0.3	5	3	2	sodic/-saline	a
Gleyic Phaeozems	Hg	0.1	5	2	3	none	a
Haplic Phaeozems	Hh	0.2	5	2	2	none	ab
Luvic Phaeozems	Hl	0.2	5	2	2	phreatic	ab
Dystric Planosols	Wd	0.1	1	1	1	none	ab
Eutric Planosols	We	< 0.1	1	2	2	fragipan	ab
Gleyic Podzols	Pg	3.4	4	1	2	none	a
Humic Podzols	Ph	0.6	4	1	1	none	a
Leptic Podzols	Pl	1.2	4	1	1	none	ab
Orthic Podzols	Po	14.3	4	1	1	stony	a/b
Placic Podzols	Pp	0.3	10	1	1	none	b
Dystric Podzoluvisols	Dd	3.3	2	1	2	none	ab
Eutric Podzoluvisols	De	12.1	3	1	2	none	a
Gleyic Podzoluvisols	Dg	0.2	8	1	1	none	ab

Soil unit name	Symbol	Area (%)	O.M. (%)	pH class	Texture class	Phase (>20%)	Slope
Rankers	U	0.3	3	2	2	stony	bc
Calcic Regosols	Rc	0.3	1	3	3	stony	bc
Eutric Regosols	Re	0.3	1	2	3	none	b
Gelic Regosols	Rx	1.3	10	1	1	none	a
Rendzinas	E	1.9	5	3	2	lithic/stony	abc
Gleyic Solonchaks	Zg	0.2	3	3	3	'saline'	a
Orthic Solonchaks	Zo	< 0.1	1	3	3	'saline'	a
Gleyic Solonetz	Sg	< 0.1	3	3	3	'sodic'	a
Mollic Solonetz	Sm	< 0.1	4	3	3	'sodic'	a
Orthic Solonetz	So	0.7	2	3	3	'sodic'	a
Chromic Vertisols	Vc	< 0.1	2	2	3	none	a
Pellic Vertisols	Vp	0.3	2	2	3	none	a
Haplic Xerosols	Xh	0.5	1	2	2	none	a
Calcic Xerosols	Xk	0.2	1	3	3	none	ab
Luvic Xerosols	Xl	0.5	1	2	2	sodic	ab
Gypsic Xerosols	Xy	< 0.1	1	3	3	saline	b

Appendix IV Phases of the FAO-Unesco soil units

From: **EFAOPHAS.WR1**
Date: **September 14 1993**

Reference: FAO-Unesco (1981). Soil Map of the World 1 : 5000000, Volume V Europe (table 3. pp.:30-66)

Areas in Turkey are not included in calculations

Phases:
- lit = lithic
- sto = stony
- pCa = petrocalcic
- pGy = petrogypsic
- fra = with fragipan
- phe = phreatic
- sal = saline
- sod = sodic
- none = non phases indicated, for Solonchaks and Solonetz no saline and sodic phase, respectively, are given. Normally for Lithosols no lithic phase is given. Here lithic is used to indicate "roch debris".

Area is given in millions of ha as well as percentages related to total area given on the first page.

Andosols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Th: sto	0	100	0	0	0	0	0	0	0	0.4	0.04
Tm: lit	100	0	0	0	0	0	0	0	0	1.2	0.11
To: non	0	0	0	0	0	0	0	0	100	0.1	0.01
Tv: non (lit)	9	0	0	0	0	0	0	0	91	2.4	0.23
								Total:		4.1	0.40

Arenosols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Qc: non	0	0	0	0	0	0	0	0	100	2.1	0.21
Ql: non (lit)	16	0	0	0	0	0	0	0	84	0.5	0.05
								Total:		2.6	0.25

Cambisols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Bc: non	0	0	0	0	0	0	0	0	100	4.1	0.40
Bd: non/sto (lit)	13	39	0	0	0	0	0	0	49	59.1	5.77
Be: non/sto (lit)	11	41	0	0	0	0	0	0	48	48.2	4.70
Bg: non	0	0	0	0	0	0	0	0	100	4.3	0.42
Bh: sto (non)	0	90	0	0	0	0	0	0	10	9.2	0.90
Bk: sto (sal/pca)	2	83	5	0	0	0	8	0	2	24.2	2.36
Bv: non (lit)	5.6	0	0	0	0	0	0	0	94.	4.8	0.47
								Total:		153.9	15.01

Chernozems		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Ch: non (sod)	0	0	0	0	0	0	0	10	90	54.0	5.26
Ck: non/phr/sal	0	0	0	0	0	37	24	0	39	7.1	0.69
Cl: non (sodic)	0	0	0	0	0	0	0	17	83	36.0	3.51
								Total:		97.1	9.46

Fluvisols		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Jc:	0	0	0	0	0	0	7	5	88	11.0	1.07
Jd:	0	0	0	0	0	0	0	0	100	0.0	0.00
Je:	0	0	0	0	0	0	6	1	93	27.5	2.68
								Total:		38.5	3.76

Gleysols		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Gc: not occurring	0	0	0	0	0	0	0	0	100	0.0	0.00
Gd: non (sto)	0	7	0	0	0	0	0	0	93	2.5	0.25
Ge: non	0	0	0	0	0	0	0	0	100	6.2	0.60
Gh: non	0	0	0	0	0	0	0	0	100	1.9	0.18
Gm: non (sod)	0	0	0	0	0	0	0	11	89	7.9	0.77
Gx: not occurring	0	0	0	0	0	0	0	0	100	0.0	0.00
								Total:		18.5	1.81

Histosols		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Od: non	0	0	0	0	0	0	0	0	100	22.1	2.15
Oe: non	0	0	0	0	0	0	0	0	100	1.4	0.13
Ox: non	0	0	0	0	0	0	0	0	100	8.2	0.80
								Total:		31.7	3.09

Kastanozems		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Kh: sod (non/sal)	2	0	0	0	0	0	8	81	10	39.2	3.83
Kk: sod (sal)	0	0	0	0	0	0	9	91	0	4.5	0.44
Kl: sod (sal)	0	0	0	0	0	0	9	91	0	6.3	0.61
								Total:		50.0	4.87

Lithosols		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
I: non (rdb/sto)	5	8	0	0	0	0	0	0	87	58.1	5.66
								Total:		58.1	5.66

Luvisols		**Percentages**								**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
La:	0	0	0	0	0	0	0	0	100	0.0	0.00
Lc: sto/non (pca)	0	62	5	0	0	2	0	1	30	16.3	1.59
Lf: sto	0	100	0	0	0	0	0	0	0	0.4	0.04
Lg: non (phr)	1	2	0	0	2	13	0	0	83	36.9	3.60
Lo: non (lit/sto)	1	2	0	0	0	0	0	0	96	64.2	6.26
Lv: non (lit)	3	0	0	0	0	0	0	0	97	1.2	0.11
								Total:		119.1	11.61

Phaeozems	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Hc: sod/non/sal	0	0	0	0	0	0	30	36	34	3.2	0.31
Hg: non (sod/sal)	0	0	0	0	0	0	14	18	68	1.5	0.15
Hh: non	0	0	0	0	0	0	0	12	88	2.4	0.23
Hl: non/phr	0	0	0	0	0	21	0	0	79	2.2	0.21
								Total:		9.2	0.90

Planosols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Wd:	0	0	0	0	0	0	0	0	100	1.3	0.13
We:	0	0	0	0	68	0	0	0	32	0.6	0.05
								Total:		1.9	0.18

Podzols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Pg: non (sto)	0	0	0	0	0	0	0	0	100	35.2	3.43
Ph: non (sto)	0	1	0	0	0	0	0	0	99	6.5	0.64
Pl: non (sto)	0	10	0	0	0	0	0	0	90	12.0	1.17
Po: non/sto (lit)	1	48	0	0	0	0	0	0	51	147.6	14.39
Pp: non (lit)	5	0	0	0	0	0	0	0	95	3.0	0.30
								Total:		204.4	19.93

Podzoluvisols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Dd:	0	0	0	0	0	0	0	0	100	34.4	3.36
De:	0	0	0	0	0	0	0	0	100	124.5	12.14
Dg:	0	0	0	0	0	0	0	0	100	2.1	0.20
								Total:		161.0	15.70

Rankers	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
U: sto	0	100	0	0	0	0	0	0	0	3.1	0.30
								Total:		3.1	0.30

Regosols	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Rc: non/sto (sod)	0	21	0	0	0	0	0	17	62	3.4	0.33
Re: non	0	0	0	0	0	0	0	0	100	3.0	0.30
Rx: non	0	0	0	0	0	0	0	0	100	13.8	1.34
								Total:		20.2	1.97

Rendzinas	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
E : non/lit/sto	38	22	0	0	0	0	0	0	40	19.3	1.89
								Total:		19.3	1.89

Solonchaks	**Percentages**									**area**	
	lit	**sto**	**pCa**	**pGy**	**fra**	**phe**	**sal**	**sod**	**non**	**(Mha)**	**%**
Zg:	0	0	0	0	0	0	0	0	100	1.6	0.15
Zo:	0	0	0	0	0	0	0	0	100	0.6	0.06
								Total:		2.2	0.21

Solonetz		Percentages								area	
	lit	sto	pCa	pGy	fra	phe	sal	sod	non	(Mha)	%
Sg: non	0	0	0	0	0	0	0	0	100	0.0	0.00
Sm: non	0	0	0	0	0	0	0	0	100	0.6	0.06
So: non	0	0	0	0	0	0	0	0	100	7.3	0.71
								Total:		7.9	0.77

Vertisols		Percentages								area	
	lit	sto	pCa	pGy	fra	phe	sal	sod	non	(Mha)	%
Vc: non	0	0	0	0	0	0	0	0	100	0.7	0.07
Vp: non (sod)	0	0	0	0	0	0	0	11	89	3.1	0.30
								Total:		3.8	0.37

Xerosols		Percentages								area	
	lit	sto	pCa	pGy	fra	phe	sal	sod	non	(Mha)	%
Xh: non (sal)	0	0	0	0	0	0	23	0	77	5.2	0.51
Xk: non (sto)	0	19	0	0	0	0	0	0	81	2.3	0.23
Xl: sod/non	0	0	0	0	0	0	0	57	43	4.6	0.45
Xy: sal	0	0	0	0	0	0	100	0	0	0.3	0.03
								Total:		12.5	1.22

Appendix V Calculation of the texture class of FAO-Unesco soil units

From: **EFAOTEXT.WR1**
Date: **Semptember 15 1993**

Reference: FAO-Unesco (1981). Soil Map of the World 1 : 5000000, Volume V Europe (table 3. pp.:30-66)

Areas in Turkey are not included in calculations

Major texture classes are given in order of importance, between brackets the minor texture classes (<20%) are given

SubT = total % of all subclasses
reduced class = reclassification to 3 class texture system
  1: Mainly sandy soils
  2: Mainly loamy soils, or as much sandy as clayey soils
  3: Mainly clayey soils

CONTENT *Available* non-available

	Text Class		Text Class
Acrisols[*2]	2	*Planosols*	
Andosols		*Podzols*	
Arenosols		*Podzoluvisols*	
Cambisols		Rankers[*3]	2
Chernozems[*1]	2	*Regosols*	
Fluvisols		*Rendzinas*	
Gleysols		*Solonchaks*	
Greyzems[*2]	2	*Solonetz*	
Histosols	not relevant	*Vertisols*	
Kastanozems[*2]	2	*Xerosols*	
Lithosols		Yermosols	not occurring
Luvisols			
Nitosols	not occurring		
Phaeozems			

*1 only 1 map unit has a text. class of 3 (Cl-unit, < 1% of that unit)
*2 all european map units have this text. class
*3 only 1 map unit has a text. class of 1 (about 10%)

SUMMARY

Andosols	Percentages			Reduced classes		
----------	First	Second	SubT	old	new	Change
Th: 2	100	0	0	2	2	n
Tm: 2	100	0	0	2	2	n
To: 2/3	100	0	0	3	3	n
Tv: 1 (2)	91	0	9	1	1	n

Arenosols	Percentages			Reduced classes		
----------	First	Second	SubT	old	new	Change
Qc: 1	100	0	0	1	1	n
Ql: 1	100	0	0	1	1	n

Cambisols	Percentages			Reduced classes		
-------------------	First	Second	SubT	old	new	Change
Bc: 3-2/3	63	37	0	3	3	n
Bd: 2-1/2	54	46	0	1	2	y
Be: 2-2/3 (1/2)	46	40	14	2	2	n
Bg: 2 (3)	84	0	16	2	2	n
Bh: 2 (1-1/2)	90	7	3	2	2	n
Bk: 2/3-2	54	46	0	2	3	y
Bv: 3-2	50	50	0	3	3	n

Fluvisols	Percentages			Reduced classes		
----------	First	Second	SubT	old	new	Change
Jc: 1/3-1/2 (2/3-3)	57	25	18	2	2	n
Jd: 2	100	0	0	2	2	n
Je: 2/3 (1)	99	0	1	3	3	n

Gleysols	Percentages			Reduced classes		
----------	First	Second	SubT	old	new	Change
Gc: not occurring	0	0	0	3	3	n
Gd: 2/3-2	72	28	0	3	3	n
Ge: 2/3-3-2(1/2)	35	30	10	3	3	n
Gh: 2 (3-2/3)	77	0	23	2	2	n
Gm: 2/3	100	0	0	3	3	n
Gx: 2-1	67	33	0	2	2	n

Luvisols	Percentages			Reduced classes		
-------------------	First	Second	SubT	old	new	Change
La: 2	100	0	0	2	2	n
Lc: 2/3-2 (3)	75	23	3	3	3	n
Lf: 2/3	100	0	0	3	3	n
Lg: 1-2/3 (2)	42	42	16	2	2	n
Lo: 2(1/2-3-1-1/2)	88	0	12	2	2	n
Lv: 2 (3)	97	0	3	2	2	n

Phaeozems	Percentages			Reduced classes		
----------	First	Second	SubT	old	new	Change
Hc: 2/3-2-1	36	34	30	3	2	y
Hg: 3 (2-2/3)	75	14	11	3	3	n
Hh: 1/3-2/3 (3-2)	49	43	8	2	2	n
Hl: 1/3 (2)	95	0	5	2	2	n

Planosols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Wd: 1-2	59	41	0	1	1	n
We: 2	100	0	0	2	2	n

Podzols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Pg: 2-1/2	62	38	0	2	2	n
Ph: 1 (1/2)	99	0	1	1	1	n
Pl: 1 (1/2)	99	0	1	1	1	n
Po: 1/2-1 (2)	52	46	2	1	1	n
Pp: 1 (2)	95	0	5	1	1	n

Podzoluvisols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Dd: 2 (1/2-1)	95	0	5	2	2	n
De: 2-1 (1/2)	71	26	3	1	2	y
Dg: 1-2	72	28	0	1	1	n

Regosols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Rc: 2/3-1-2	52	28	20	3	3	n
Re: 2/3 (2-1)	78	16	5	3	3	n
Rx: 1/2	100	0	0	1	1	n

Rendzinas		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
E : 2-2/3	63	37	0	2	2	n

Solonetz		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Sg: 3	map information non Europe			3	3	n
Sm: 3	100	0	0	3	3	n
So: 2/3	100	0	0	3	3	n

Solonchaks		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Zg: 3 (2-2/3)	90	7	3	3	3	n
Zo: 2/3	100	0	0	3	3	n
Zt: 2-3	map info non european units			3	3	n

Vertisols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Vc: 3	100	0	0	3	3	n
Vp: 3	100	0	0	3	3	n

Xerosols		Percentages		Reduced classes		
	First	Second	SubT	old	new	Change
Xh: 2-1 (3)	65	21	14	2	2	y
Xk: 3 (2/3-2)	66	19	15	3	3	n
Xl: 2	100	0	0	2	2	n
Xy: 2/3	100	0	0	3	3	n

Appendix VI Illustration of regional mismatch of generalized soil maps: the Icelandic case

VI.1 Introduction

For the production of the generalized soil map of Europe the NOAA digital map of a 10-minute grid was used as basic material. At that time the FAO-Unesco soil map of the world was not available as a digital map at RIVM. Nevertheless the hard copy of that map was available and has been used for corrections and basic information for soil units.

A review at RALA (Agricultural Institute of Iceland) of the generalized soil map, as part of a total review of the Dobris report, showed that the generalized map provided by RALA for Iceland strongly deviated from the reviewed map. In *Figures VI.1* and *VI.2* both maps are given. In *Figure VI.3* the FAO-Unesco map is shown. In addition to the generalized map of RALA a soil map (Nygard, 1959) as well as several pedon descriptions (Arnalds et al., 1993; Wada et al., 1992) have been provided by RALA.

VI.2 Causes of mismatch

At least two causes of mismatch of the generalized maps on a regional scale can be distinguished:

(1) Scale of generalization: due to the generalization process on the European scale on regional level mismatch will occur with maps generalized on a regional scale;
(2) Errors in basic information: the european soil map used is relatively old (1981). In several regions more up to date information on occurring soils may be available.

For the Icelandic case both causes seem to occur. Sometimes it is not possible to find out which of the two is the cause; both may be possible.

VI.3 Discussion

Lithosols are soils with a limited depth (<10 cm soil over continuous hard rock). These soils cover to a large extent Iceland (map unit I-2bc), but occur o.a. in Scandinavia, the Alps and the Ural. The characteristic are largely determined by the parent material which is highly variable. Based on very general information these soils are put in the class of acid shallow and stony soils. Comparing the generalized maps these soils should be classified in the eastern and western part as non-acid loams, in the central part as non-acid stony soils and in the east central part, just north of the Vatnajökull glacier as sandy soils (see *Figure VI.2*). Using the information of the Nygard (1959) soil map the problem may be exaggerated by a too rough generalization. The main point in that case is that the Icelandic lithosols are non-acid instead of acid shallow and stony soils.

The Vitric Andosols of Iceland (Tv33-1ab map unit), looking at the provided generalized soil map, should be classified (1) as non-acid stony in the central part, (2) as sandy soils in the southern part and in the east central part, just north of the Vatnajökull glacier (see *Figure VI.2*) and (3) as non-acid loamy soils in the eastern part. According to the FAO-Unesco map (1981) it are non-shallow, non-stony sandy soils. No specific Icelandic profile data were available at our institute, but according to the available profiles from other regions Vitric Andosols and Andosols in general contain relatively much organic matter. Vitric Andosols are, according to our information usually non-acid. For these reason they have been put together with the 'Black earths'. The profile information provided by RALA indicate that the Andosols on Iceland have a 25-75 thick A-horizon with an organic matter content ranging from 3.7 to 16%. The estimated organic matter content used for the Vitric Andosols of 8% seems reasonable. The pH_{KCl} of the top soil is usually between 5.1 and 5.7 (slighly acid). The Icelandic Andosols are mostly loamy. For this reason they could still be classified in the category of the Black earths. Due to the lack of vegetation, the Icelandic soils in general are rather vulnerable to wind erosion (Arnalds, 1993), for this reason the Andosols could be classified as non-acid loamy soils.

The Orthic Podzols on Iceland (Po2-1b) are indeed mainly wet (symbol of "swampy" areas), but this also hold for part of the Po units in Finland. Nevertheless, the largest area of the Podzols is not wet. Also for other soil units, part of map units occur with a symbol indicating wetness and it was not possible to incorporated this information within a short time. In addition, the symbol used to indicate "swampy" areas probably is derived from general topographic maps, because it is not included in the legend nor under phases nor under miscellaneous land units. The reviewer states that "*Up to this point no one has ever shown the existence of Podzols in Iceland, and I really doubt that they exist in any considerable areas. There has been a considerable amount of confusion among foreigners visiting the country without adequate background, and light coloured tephra (volcanic ash) layers have been mistaken for eluvial horizons.*". Looking at the provided soil map and combining this information with the information on the map of the FAO-Unesco from 1985, I would suggest that soils mapped on the FAO-Unesco map as 'wet' orthic podzols are probably Humic Gleysols, if the histic H is dystric and Mollic Gleysols if the histic H is eutric (FAO-Unesco legend of 1974). They have a peat layer (most of them are classified as peat soil on the soil map of Iceland, 1959) which is to thin to classify them as Histosols. If peat is present there should be hydromorphic properties as well. The mineral horizon is mainly coarse textured, which is in accordance with the texture class of the podzols on the FAO-Unesco map. In the FAO system they do not classify as Andosols because soils showing hydromorphic properties are separated before hand. In addition Andosols can not have a Histic H horizon. The organic soils on the FAO-Unesco map are classified as Dystric Histosols, this could indicate that histic H are dystric.

Humic Cambisols (Bh26-1ab) are advised to be included, for the largest part, in the non-acid loamy soils. The FAO-Unesco map information indicated that in Iceland they are sandy soils (**1** in Bh26-**1**ab stands for coarse texture of topsoil) and the classification indicate that they are acid; else they should have been classified as Eutric Cambisols (FAO-Unesco, 1974). The umbric A horizon indicates a base saturation of less then 50% (FAO-Unesco, 1974) and the pH_{salt} will usually be 4.5-5.5 for agricultural land (below 4 for non agricultural land). This is based on the relationship found (86 profiles) between base saturation and pH; the base saturation is mostly based on CEC_{sum} rather than CEC_{NH4OAc}, and pH will probably be lower if based on CEC_{NH4OAc}. In our data base of almost 350 European and another 130 non European (mainly US) profile data, only for 2 Humic Cambisol profiles data are available. Both profiles are under grass and have a pH_{KCl} of 4.6 (Spain) and 3.5 (Porto Rico), respectively. Soils mapped as Humic Cambisols (coarse textured) are on the Icelandic soil map 'silty soils', i.e. medium textured. If parent material is volcanic and their bulk density is less than 0.85 g/cm^3 - which seems the case looking at the profiles information provided - they should be Humic Andosols.

The Histosols (Organic soils; map unit Od24-a) are partly indicated by the Icelandic reviewers as wet soils in stead of Peat and Muck soils. In the eastern part it seems that a small area has been forgotten.

The glaciers do occur on the FAO-Unesco map (1981), but do not show on the digital map (NOAA, 1991). On this map they show as Lithosols. Because the NOAA map has been used to make the generalized map, the glaciers do not show on the generalized soil map.

The 'strip' of sandy soils south of the southern wet soil area on the map provided by Iceland consist on the FAO-Unesco map of Vitric Andosols (Tv33-1ab) and of Ortic Podzols (Po2-1b) which are both sandy.

The conclusion of the Icelandic comments are that instead of the 2.2 million ha of Andosols (FAO-Unesco, 1985, Soil Map of the World Volume V Europe) there are about 6 million ha of Andosols on Iceland. In addition that there are (almost) no podzols on Iceland, and that the light tephra layer has been mistaken for an eluvial horizon. Further the parent material of the Icelandic soils is non-acid. It seems that the soils of Iceland have been misclassified in the past.

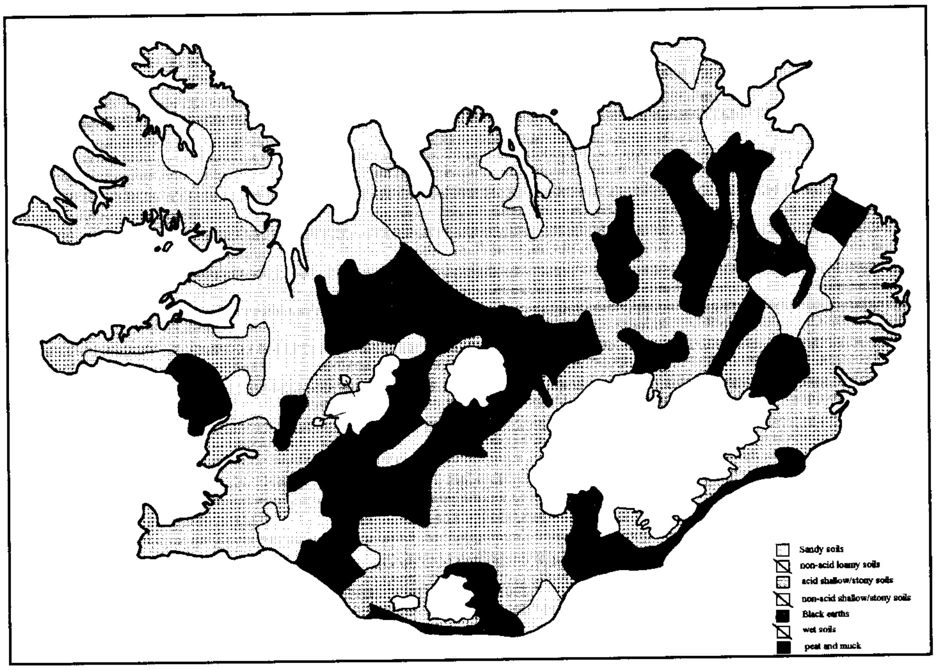


Figure VI.1 *Generalized soil map of Iceland, based on FAO soil map of Europe (1981)*

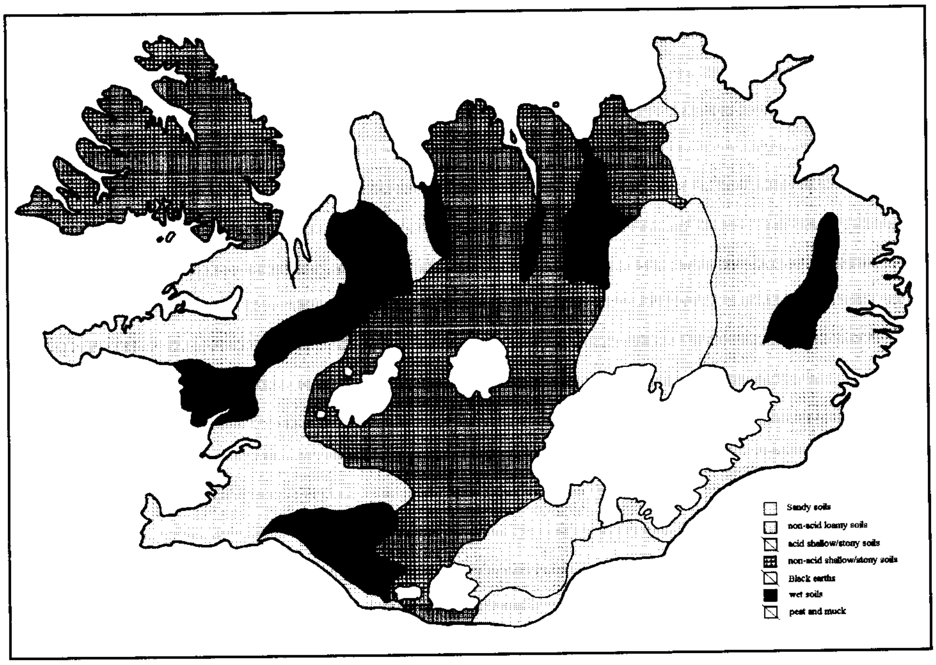


Figure VI.2 *Generalized soil map of Iceland by RALA, based on the soil map by Nygard (1959)*

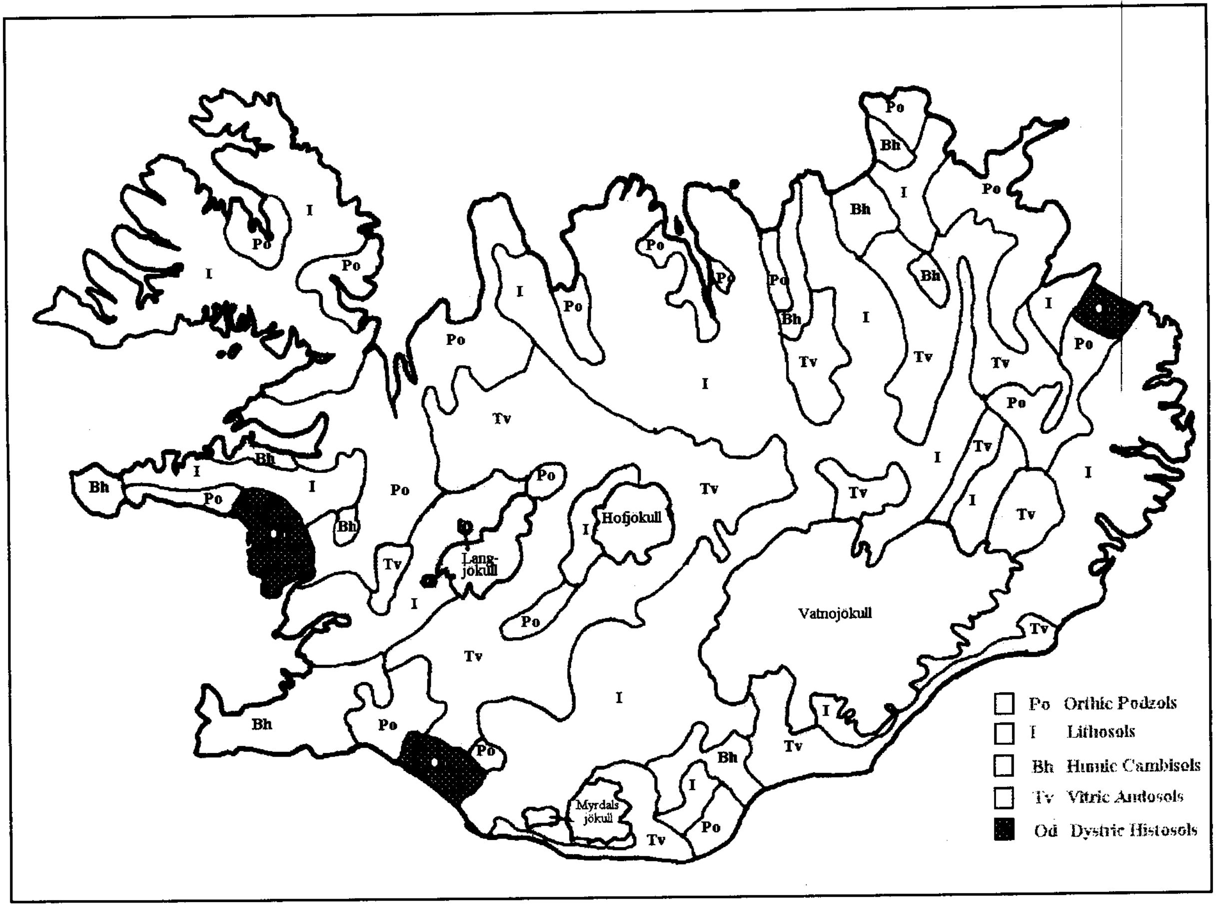
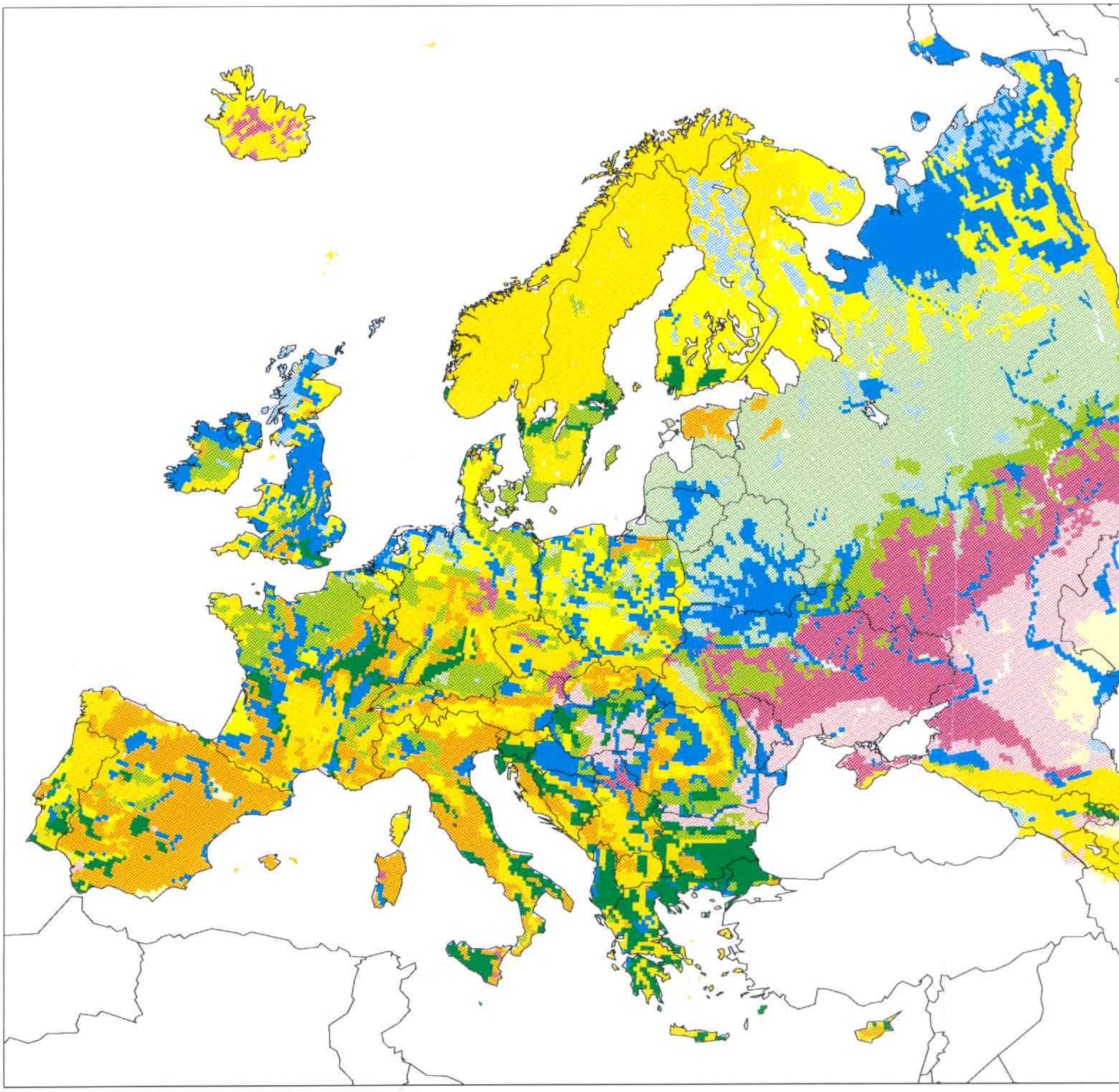
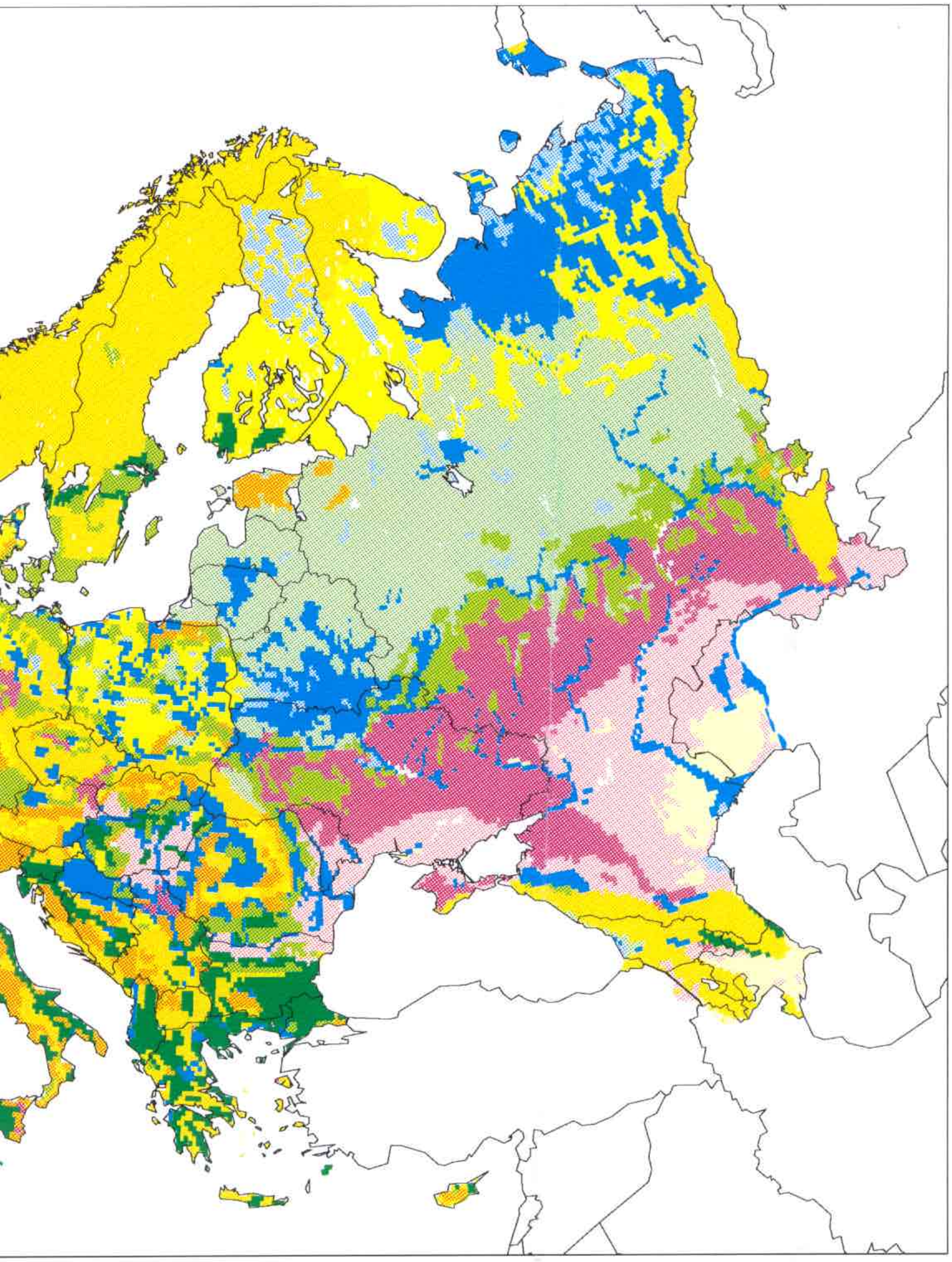


Figure VI.3 Soil map of Iceland (FAO, 1981)

Generalized Soil Map of Europe



Appendix I (RIVM report number 481505006) e



Reduced and simplified from the FAO–UNESCO soil map of the world (FAO, 1971–1981) with amendements based on additional soil information and using the NOAA (1991) digitized version of the map.

Computations: RIVM

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