Appraisal of World Reference Base for Soil Resources - from a nordic point of view

Geografisk Tidsskrift, Bind 100 (2000)

Appraisal of World Reference Base for Soil Resources - from a nordic point of view

Mogens H. Greve, Markku Yli-Halla, Aage A. Nyborg, Ingrid Öborn

Abstract

During the project "Nordic Reference Soils" 13 different soils from Denmark, Finland, Norway and Sweden were selected in order to represent i) soils covering the main areas of the Nordic area, ii) soils from the different climatic regions, and iii) environmental sensitive soils. The 13 Nordic Reference Soils provided an excellent basis for the evaluation of the WRB (World Reference Base for Soil Resources) performance under Nordic conditions. Classification according to the WRB poses considerable problems. These concern podzolized soils, cultivated soils, and the acid sulfate soils. Only three out of the seven podzolized soils are allocated in taxons reflecting that they were podzolized. Four out of the nine cultivated soils were exposed to substantial anthropogenic impact, resulting in man-made Mollic A-horizons, which is not reflected in the classification. The WRB-classification of the soils is compared with the FAO and Soil Taxonomy classification. This highlighted some of the classification problems. This paper will propose changes to the WRB in order to improve the performance of the system for Nordic soils.

Keywords

WRB, Soil Classification, Nordic Soils, Anthropogenic impact, Podzols, Acid Sulphate soils.

Mogens H. Greve, Danish Institute of Agricultural Sciences (DIAS), Dept. of Agricultural Systems, P.O. Box 50, DK-8830 Tjele, Denmark.
Markku Yli-Halla, Agricultural Research Centre of Finland (MTT), FIN-31600 Jokioinen, Finland.
Aage A. Nyborg, Norwegian Institute of Land Inventory (NIJOS), P.O. Box 115, N-1430 Ås, Norway.
Ingrid Öborn, Swedish University of Agricultural Sciences (SLU), P.O. Box 7014, SE-750 07 Uppsala, Sweden

Geografisk Tidsskrift, Danish Journal of Geography 100: 15-26

There is an increasing demand for pedological information in the monitoring of changes in the environment, planning for sustainable land use, vulnerability mapping and environmental risk assessment. Detailed soil information is needed in mathematical simulation models for designing scenarios e.g., of nutrient or pesticide loading of the environment and even global climate change.

Soil maps are the traditional sources of soil information. The soils of the Nordic countries are displayed on the generalized FAO/Unesco Soil Map of the World (FAO, 1974) and later in a more detailed soil map of Denmark, Finland, Norway and Sweden (Rasmussen et al., 1989). The EU soil map (1:1 000 000) was published in 1985 (CEC, 1985) and digitised 1986. This map formed the basis for the EU Soil Geographical Database, which was later extended to cover most of Europe (The European Geographical Database). A European soil map, including the Nordic countries (exclud ing Iceland) was presented at the 16th World Congress of Soil Science in Montpellier, France 1998 (European Soil Bureau, 1998).

Efforts to build a comprehensive geographical land information system, partly consisting of different soil data bases, are being co-ordinated by the European Soil Bureau (Heineke et al., 1998). In connection with this land information system, a European soil profile analytical database is currently being established (Breuning-Madsen and Jones, 1995). Information about typical soil profiles of Europe has been provided through the EURO-soil project (Kuhnt and Muntau, 1994) where five soil types covering a large part of western and southern Europe have been selected. The EURO-soils were characterised as reference soils for environmental risk assessments for chemicals, i.e. pesticides.

In order to include a typical Nordic soil in the EURO-soil collection, the Nordic Reference Soils project was started in 1995 (Tiberg et al., 1998). In contrast to the rest of Europe, the parent material of most soils in Denmark, Finland, Norway and Sweden were deposited during and after the Weichselian glaciation. Glacial tills derived from the bedrock of the Baltic Shield, dominated by acidic granitic and gneissic Precambrian rock, form the most common parent materials, particularly in Finland, Sweden and parts of Norway. Rocks of the Caledonian Mountain Range, which have a composition ranging from acid quartzite to ultra-basic amphibolite, dominate the western parts of the Scandinavian Peninsula. Younger sedimentary deposits prevail in Denmark and southern Sweden, both south of the Baltic Shield, but also present are quaternary deposits, which to a large extent originate from the Weichselian glaciation. Soils have thus only been subject to pedogenesis for a relatively short period. The only exception is in western Jutland in Denmark where Saalean deposits occur. Unlike the rest of Europe, extensive peatlands are typical in northern Finland and Sweden.

In the Nordic countries, agriculture is concentrated in the low lands where young, fine and medium textured marine and fluvial sediments have been deposited. In Denmark, more than 60% of the land area is cultivated, whereas in Finland, Norway and Sweden, less than 10% is used for agriculture. In Finland and Sweden, more than 60% of the country is forested while more than half of Norway is mountainous. Except for Russia, Finland, Norway and Sweden have a lower population density than the rest of Europe, and it is, therefore, that the soils of these countries have experienced a minimum impact of anthropogenic activities.

The aim of this paper is to test the performance of World Reference Base of Soil Resources (WRB) (FAO, 1998) on 13 typical and widespread Nordic soils. The soils were classified according to the WRB, the FAO/Unesco Soil Map of the World (FAO, 1988) and Soil Taxonomy (Soil Survey Staff, 1998). The differences in classification were then compared. Revisions to WRB were proposed in order to improve the ability of this system to reflect important properties of Nordic soils.

Materials and methods

Selection of soils

The 13 Nordic Reference soils were selected in order to cover the main soil types of the Nordic countries reflecting the main variations in parent material, climatic zones, land use regimes, soil profile development and soil properties.

In Denmark, the selection of the soils was based on information derived from the Danish Soil Profile Database. This database became nation-wide during a campaign from 1987 to 1989, where approximately 900 profiles from the intersections in a 7-km grid were described and analysed. Detailed knowledge of the soil types on the research stations of the Danish Institute of Agricultural Sciences, were also used (Dissing Nielsen & Møberg1984; 1985).

In Finland, the background for the selection of soils was the database of glacial tills (Lintinen, 1995), data describing the distribution of the types of agricultural soils in Finland (Kähäri et al., 1987) and a survey of the research stations of the Agricultural Research Centre of Finland (Urvas, 1995).

In Norway, the NIJOS Soil Information System and soil data from the Monitoring of Forest Health project, formed the basis for the selection of the reference soils. The Soil Information System covers one third of the agricultural area of Norway on a 1:5000 scale, and the forest soil database includes more than 1000 soil profiles from the intersections in a 9 km grid.

The selection of Swedish forest soils was based on the Forest Soil Inventory database which includes 23 500 sites. As for agricultural soils, the frequency of different soil types was roughly estimated, based on the Ekström's (1953) soil map, where he divided Sweden into regions of cultivated soils according to surface-soil type. These estimations were combined with information from agricultural statistics (Statistic Sweden, 1993) on the areas of agricultural land within each region. Most of the reference soils represent soils occurring in several of the Nordic counties.

Soil descriptions and analyses

The profile descriptions were made in accordance to the FAO guidelines (FAO, 1990). Soil colours were determined according to the Munsell Soil Color Charts (1994).

The physical and chemical characteristics were determined at each national soil laboratory with slight deviations in methodology from one laboratory to another. The methods were generally as follows: Organic carbon was determined by dry combustion, taking into account the content of carbon in a calcareous soil (Flakkebjerg, No 2,). Soil pH was determined in a water suspension and/or in 0.01 M $CaCl_2$ (solution-to-soil ratio 1:2.5). Particle size distribution of the material <2 mm was determined by sedimentation after an appropriate dispersion. Poorly crystalline Fe and Al (hydr)oxides were extracted in the dark with 0.2 M oxalate (pH 3.0) (McKeague & Day, 1966). Cation exchange capacity (CEC) and exchangeable Ca, Mg, Na and K were determined by the ammonium acetate method at pH 7.0 (Thomas, 1982) and acidity was determined by titrating the extract to pH 7.00.

Other determinations also, required for correct classification, were carried out. These include the following: Phosphorus was extracted with 1% citric acid (van Reeuwijk, 1995) from the dark Ap-horizons in order to differentiate between the mollic and anthropic horizons. Soil pH was determined in a water-to-soil suspension of 1:1 in samples taken from the Bhs and Bs-horizons. pH was also determined on fresh samples of the acid sulfate soil (Ylistaro, No 6) which were also analysed for sulfate extracted with 0.01 M CaCl2 (Yli-Halla, 1987) after aerobic incubation of 2 months. These results support the classification of the soils and the data are presented in details in Tiberg et al (1998).

Results

The locations of the 13 soils are shown in Figure 1 and their classification is presented in Table 1. The descriptions of the 13 Nordic soils are presented in detail elsewhere (Tiberg et al. 1998), and an example of this is shown in Figure 2. Data of the 13 soils are summarised in Table 2 and the profiles are displayed in Figure 3.

Podzols, with an organic surface horizon (mor layer), are the typical soils found in coniferous forests in Sweden, Norway and Finland. These areas are represented by the Kloten soil (No. 11). The Sodankylä soil (No. 5) was selected from a glacial till area in northern Finland to represent a northern type of podzol, where owing to the slow soil forming processes, the illuvial horizon (Bs) is less developed than in the Kloten soil type. Froland (No. 9) from southern Norway is an example of a poorly drained podzol. It represents the more humid (oceanic) areas in the southern and western parts of the Nordic countries, which also include the areas that are most exposed to acid rain.

Most Nordic podzols are developed in glacial till from Precambrian acidic bedrock, i.e. granite and gneiss. To represent the soils developed in parent material originating from the Caledonian mountain range, the Blomhöjden soil (No. 12) was included. It also represents ecosystems sensitive to long-range transport of pollutants, i.e. radionuclides from the atomic bomb tests during the 1960's and the Chernobyl fallout in 1986. The Jyndevad soil (No. 1) represents soils developed on glaciofluvial deposits. Mikkeli (No. 4) and Borris (No. 3) are developed on glacial till, both representing agricultural soils.

The Borris and Mikkeli soils represent relatively weakly podzolized soils developed on well-drained sandy material. Tillage has incorporated the E and partly the Bhs-horizons, into in the Ap-horizon. These soils qualify as Inceptisols in the Soil Taxonomy with a mollic epipedon overlying a base-depleted subsoil. They are classified as Cambisols in WRB.

The Flakkebjerg soil (No. 2) represents one of the most fertile soil types in the Nordic area. These soils are formed in loamy calcareous glacial tills dominated by material derived from Cambrian bedrock, and are frequently found in eastern Denmark and southwestern Sweden. Another fertile soil type is the Cambisol represented by the Lanna soil (No. 13). These soils are found on glacial and postglacial clays in isostaticly uplifted areas in southwestern Finland and in southern and central Sweden. Agriculture is the dominant land use on these soils . The most important soils for crop production in Norway are the silty and clayey soils of marine origin, represented by the Ås soil (No. 10), and the loamy alluvial soils, represented by the Hole soil (No. 8).

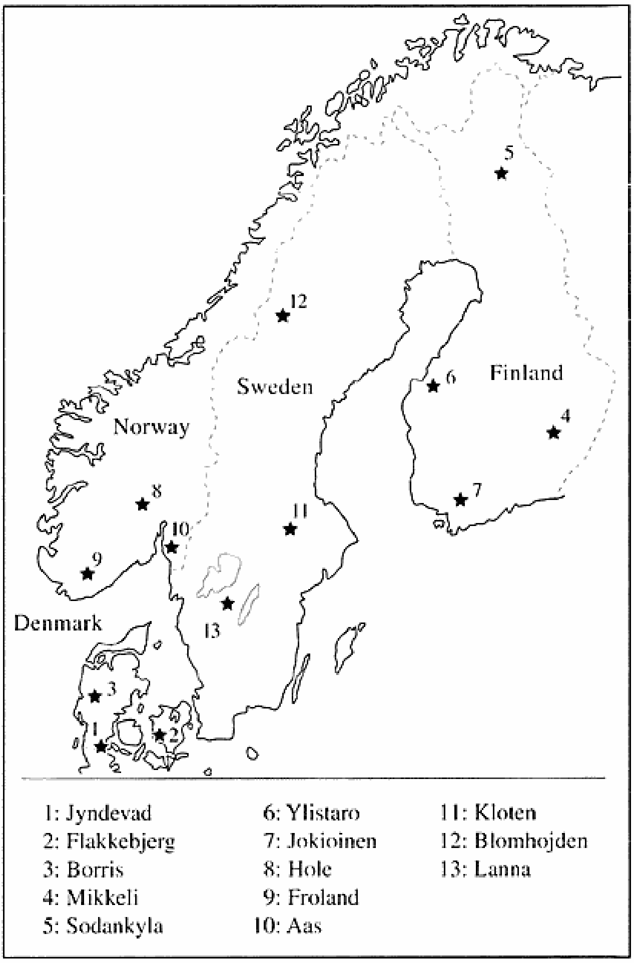


Figure 1:

Acid sulphate soils, found in isostatic uplifted areas, along the coasts of the Gulf of Bothnia (Purokoski, 1959; Larsen,1978; Öborn, 1989; Öborn, 1994; Yli-Halla, 1997; Yli-Halla et. al., 1999), represent a unique soil type within Europe. The Ylistaro soil (No. 6) represents a strongly developed, relatively well drained acid sulphate soil frequently found around the Gulf of Bothnia.

The peat soils (Histosols) are, after the podzols, the most frequent soil type in Finland and Sweden. Deep uncultivated peat soils, of minor economical interest for forestry and agricultural purposes are not represented in the this study. Except where peat mining has taken place, these soils are only slightly influenced by human activity. The Jokioinen soil (No. 7), consisting of Carex peat, was selected as a representative of the cultivated Nordic peat soils, soils which are commonly used for the production of potatoes and vegetables. These soils are often subject to excessive use of pesticides due to severe weed problems (i.e. Agropyron repens) and intensive cultivation. In Finland the area of cultivated Histosols or soils which have a peaty plough layer has been estimated to be 370 000 ha (Kähäri et al.,1987) and in Sweden, similar soils occur in approximately 110 000 ha (Eriksson et al., 1997).

Discussion of the WRB classification

It was possible to classify all the Nordic reference soils according to the WRB system. This is an improvement compared with the FAO system where strict horizon limitations allowed in the different soil groups make it impossible to classify some particularly coarse textured agricultural soils. For instance, the Borris soil (No. 3) is too coarse to have a cambic horizon in the FAO system and the mollic horizon excludes it from Regosols. Classification of the Nordic reference soils, presented problems with i) podzolised soils, ii) cultivated soils, and iii) acid sulphate soils.

Podzolized soils

Seven of the reference soils (1, 3, 4, 5, 9, 11 and 12) showed morphological evidence of podzolisation. WRB places three of these soils in the Podzol group and the remaining four in the Cambisol group. Soil No. 9 and No. 12, were classified as Podzols in the WRB and Spodosols in Soil Taxonomy and pose no classification problems. On the other hand soils like No. 5 and No. 11 that represent widespread soil types in Norway, Sweden and Finland, failed the podzol colour criteria in the WRB.

Table 1. The nordic soils classified using the proposed revision of the WRB the WRB98, the FAO88 and Soil Taxonomy (98).

Soil number	Reference Soil	WRB (proposed revision)	WRB(98)	FAO (88)	*Soil Taxonomy (98)*
1	Jyndevad (Dk)	Hortic Podzol	Mollic Cambisol	Haplic Podzol	*Spodic Udipsamment*
2	Flakkebjerg(Dk)	Hortic Luvisol	Glossic Phaeozem	Haplic Luvisol	*Oxyaquic Agiudolls*
3	Borris (Dk)	Hortic Cambisol	Mollic Cambisol	*Not possible*	*Oxyaquic Dystrudepts*
4	Mikkeli (Fin)	Hortic Cambisol	Mollic Cambisol	Dystric Regosol	*Oxyaquic Dystrocryept*
5	Sodankylä (Fin)	Haplic Podzol	Dystric Cambisol	Haplic Podzol	*Oxyaquic Haplocryod*
6	Ylistaro (Fin)	Endothionic Cambisol	Gleyic Cambisol	Gleyic Cambisol	*Sulfic Cryaquept*
7	Jokioinen (Fin)	Sapric Histosol	Sapric Histosol	Terric Histosol	*Terric Cryosaprist*
8	Hole (N)	Fluvic Cambisol	Fluvic Cambisol	Dystric Fluvisol	*Aquic Dystrudept*
9	Froland (N)	Gleyic Podzol	Gleyic Podzol	Gleyic Podzol	*Typic Duraquod*
10	Ås (N)	Stagnic Albeluvisol	Stagnic Albeluvisol	Stagnic Podzoluvisol	*Aeric Glossaqualf*
11	Kloten (S)	Haplic Podzol	Haplic Podzol	Haplic Podzol	*Typic Haplorthod*
12	Blomhöjden (S)	Haplic Podzol	Haplic Podzol	Dystric Cambisol	*Typic Haplocryod*
13	Lanna (S)	Eutric Cambisol	Eutric Cambisol	Gleyic Cambisol	*Typic Endoaquept*

Dk = Denmark, Fin = Finland, N = Norway, S = Sweden

According to the WRB, a spodic horizon cannot have a colour chroma higher than 4 in the hues of 7.5YR or redder, or a colour chroma higher than 3 in the hue 10YR. A colour chroma of 6 in the podzolised B-horizon is though very common in Nordic forest soils. This conclusion can be made by examining the Norwegian Forest Soil Database (NIJOS, unpublished material). The soil No. 5 fails the colour requirement due to colour chroma 6 in the Bs-horizon. Soil No. 5 though fulfilled the chemical podzol requirements, and was classified as a Spodosol in Soil Taxonomy. From a Nordic point of view, soil No. 5 is considered to be a typical podzol, and is a podzol according to the national classification systems. Podzols are important as recharge areas of ground water, and their characteristics are, therefore, very important in modelling the vulnerability of ground water resources. The restriction of colour is, therefore, unfortunate. The Podzol group in the WRB has undergone substantial changes in diagnostic criteria then compared to the FAO system. The definition of the spodic horizon is now more in line with the definition of spodic materials in Soil Taxonomy. A spodic horizon must fulfius 5 diagnostic criteria, one of which includes the above-mentioned colour requirements. These colour requirements are, with small changes, taken from the Soil Taxonomy's definition of spodic materials. On the other hand Soil Taxonomy uses these colour criteria without the support of additional chemical criteria concerning Fe and Al distribution within the profile, if an overlying albic horizon is present, and the pH and organic carbon criteria are fulfilled. With the support of fulfilled Fe and Al distribution criteria, Soil Taxonomy allows spodic materials to have colours with chroma 5 or 6 and hue of 7.5YR, with or without an overlying albic horizon. Any chroma is allowed if the hue is redder than 7.5YR.

Cultivated soils

The anthropogenic impact on Scandinavian soils goes back more than 5000 years. Humans have had both direct and indirect impact on soil and soil formation. Direct impact includes irrigation, drainage, tillage, addition of manure, earthy materials and chemicals as lime and pesticides. Indirect human influence on pedogenesis by controlling landuse, for instance, by deforestation and establishing widespread calluna heath for centuries. Tillage and tillage erosion homogenise and deepen the A-horizons, and translocate soil material downslope, a process which can create A-horizons more than 1.5 metres thick. Applications of fertiliser, manure and lime can change the chemical properties of the whole soil profile. This strong antropogenic influence creates a set of anthropogenic properties which include the formation of man-made umbric and mollic horizons, development of reverse pH profile, a raised content of phosphorous in the Ap-horizon and transport of humus-silt-clay colloids into the subsoil in pores and on pedfaces.

The mollic horizon of these soils, will after a few years of set-aside, turn into an umbric A-horizon and eventually into an ochric A-horizon (Krogh and Greve, 1999). In the Nordic countries soils are limed in cycles of approximately 4 years and the base saturation follows this cycle. In the period after liming, base saturation rises to above 50 %, after which the base saturation gradually drops to less than 50% just before liming again. Every time the base saturation of the A-horizon changes, the classification of the soil changes at the highest level in the classification system. This suggests that the base saturation is not suitable to use in order to separate the different taxons at the highest levels in the Scandinavian agricultural systems. This is described in detail in (Krogh and Greve, 1999). Soils No. 1, 2, 3 and 4 are all cultivated soils, with high contents of phosphate in the A-horizon and they are, therefore, excluded from having a mollic A-horizon in the FAO system. In the absence of the P_2O_5 limit in the WRB system, these A-horizons are now classified as mollic instead of fimic. The classification of soils No. 1, 3 and 4 is very different from their undisturbed equivalents due to the formation of artificial mollic and umbric A-horizons. Incorporation of the E-horizon and the upper part of the B-horizons often takes place under cultivation. Human influences mean that, soils No. 1, 3 and 4 all fail to qualify as Podzols. They all have a pH which is too high in the B-horizon and the criteria involving distribution of oxalate extractable Fe and Al are not met. Soils No. 3 and No. 4 do not meet the colour criteria either. Soil No. 1 has retained most of the podzol characteristics, but marginally fails the oxalate extracted Fe and Al criteria.

Acid Sulfate Soils

The Ylistaro soil represents a special problem in the classification of relatively well drained acid sulfate soils. These soils are drained by isostatic land uplift but are, in addition, often artificially drained with open ditches and/or tile drainage and used as arable land. The Ylistaro soil type has a well developed sulfuric horizon with jarosite mottles and low pH H_2O (<3.5) from the depth of 70 cm to 150 cm.

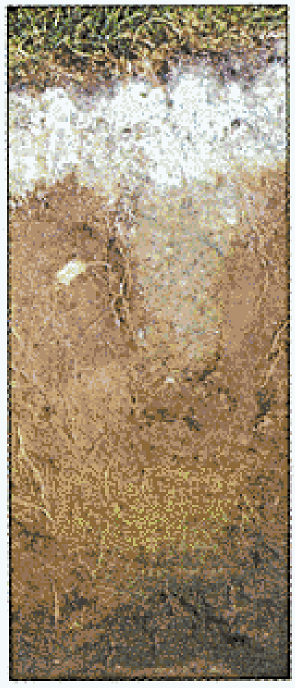
In the WRB and FAO the sulfuric horizon is only taken into account in the Histosol, Fluvisol and Gleysol soil

Soil no 12

Reference data	
Date of description	9 August 1996
Authors	Pål Andersso, Ingrid Öborn
Location and country	Blomhöjden, Sweden
Elevation	575 m
Map Sheet	22 E Frostviken SO
	716695 144810
Koordinate	14°43'24"E, 64°36'21"N
Site Information	
Landform	Hill
Topography	Slightly concave
Slope	Strongly sloping (15%)
Position on slope	Upper slope
Aspect of slope	South
Rock outcrops	None
Surface coarse fragments	Few
Vegetation	Grass and herbs, shrubs
Profile information	
Profile depth	75+ cm
Parent material	Sandy glacial hill
Effective rooting depth	51 cm
Maximum rooting	75+ cm
Drainage class	Well rined
Period of saturation	Rarely saturated
Ground wather level	Not observed (deep)
Soil classification	
USDA	Typic Haplocryod
FAO	Dystric Cambisol
WRB	Haplic Podzol
Mean annual air temp.	1.4
Mean annual precip.	754
Soil temperature regime	cryic
Soil moisture regime	udic

Figure 2:

Soil horizon description



General description:

The profile is located on the mid slope of a moraine ridge.

The soil is a rather well developed podzol derived from a parent material consisting of gravely sandy loam.

O (0-3 cm):

Very dark grayish brown (2.5 Y 3/2) moist, smooth boundary.

E (3-11 cm):

Light brownish gray (2.5 Y 6/2) moist and light gray (2.5 Y 7/1) dry, sandy loma, many fine to coarse gravel, few stones, few lage boulders, fresh to slightly weathered mica schist; moderate fine and medium granular, very friable moist, slightly hard dry, non sticky, non plastic; mostly interstitial voids; many very fine and fine roots; abrupt smooth boundary.

B_{s1} (11-26cm):

Reddish brown (5 YR 4/4) moist and dark yellowish brown (10 YR 4/6) dry, sand loam, common fine to coarse gravel, common stones and boulders fresh to slightly weathered mica schist; moderate fine and medium sub angular blocky breaking to fine granular, very friable moist, soft dry, non sticky, non plastic; mostly interstitial voids; many very fine and fin roots; gradual smooth boundary.

B_{s2} (26-51 cm):

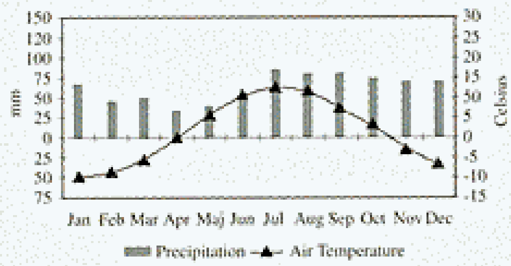
Yllowish brown (2.5 Y5/6) moist and yllowish brown (2.5 Y 5/5) dry, sand loam, common fine to coarse gravel, common stones and boulders, fresh to slightly weathered mica schist; moderate fine and medium sub angular blocky breaking to fine granular, very friable moist, soft dry, non sticky, non plastic; mostly interstitial voids; many very fine and fine roots; gradual smooth boundary.

C_g (51-75+ cm):

Olive brown (2.5 Y 4/4) moist and light olive brown(2.5 Y 5/4) dry, sand loam, many fine to coarse gravel, common stones and boulders, slightly weathered to strongly weathered mica schist; moderate very fine blocky, very friable moist, soft dry, slightly sticky, non plastic; interstitial voids plus planar voids along stone surfaces; very few fine roots.

Comments:

Tow soil profiles (pit A and pit B) have been characterised within the area used for grid sampling of the Nordic Refernce soil No12. This description is for Pit B. Analytical data are with a few exceptions (indicated in the tabel) given for soil pit.



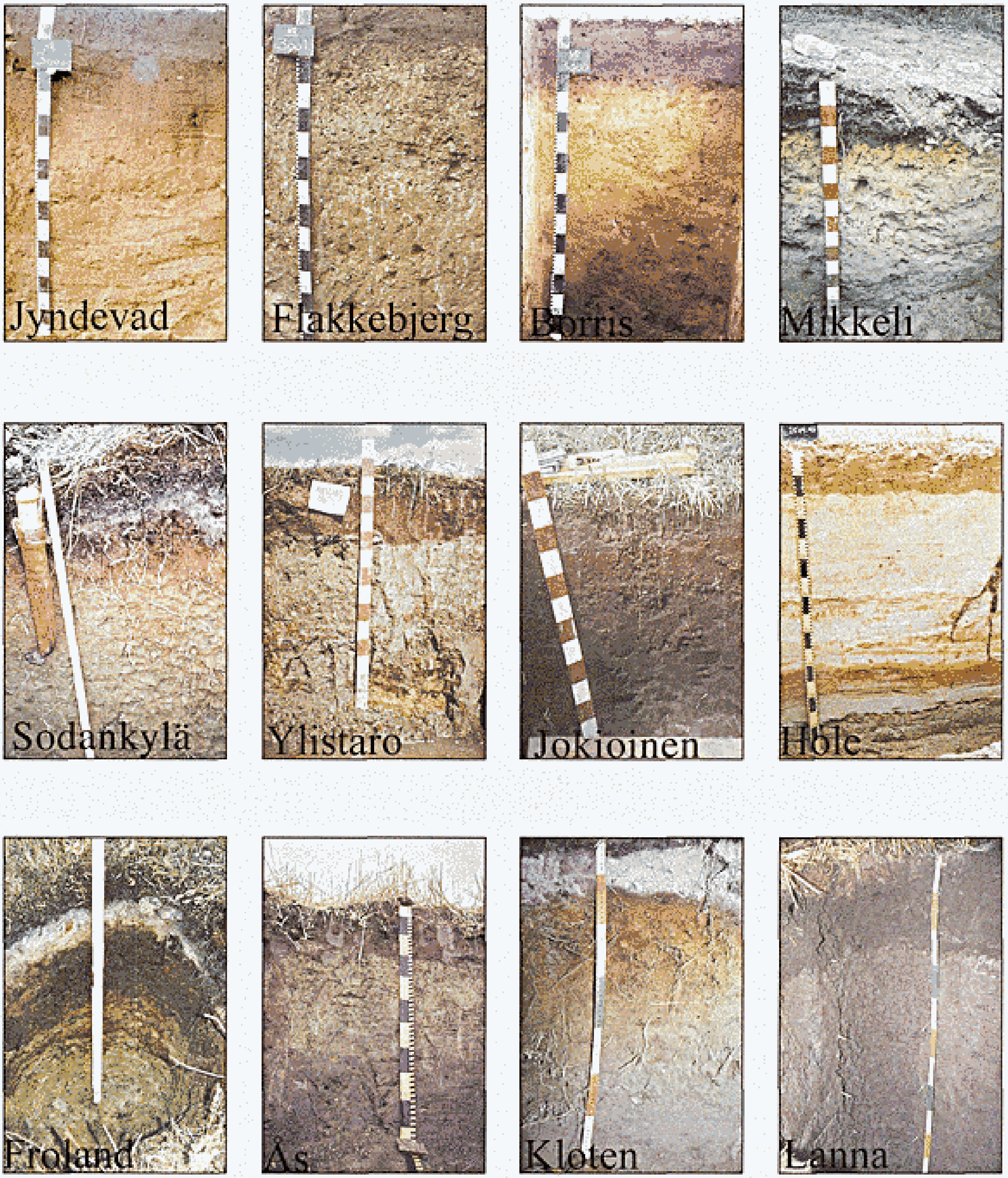

Jyndevad
Flakkebjerg
Borris
Mikkeli
Sodankylä
Ylistaro
Jokioinen
Hole
Froland
Ås
Kloten
Lanna

Figure 3:

Tabel 2:

Soil	Horizon	Depth (cm)	Colour	Org.C (%)	pH, H2O	pH, CaCl2	P, citrat mg/ kg
1 Jyndevad	Ap	0-23	10YR3/2	2.4	6.2	6.0	635
	Bhs	23-45	7.5YR3/2	1.6	6.6	5.6	250
	Bs	45-75	7.5YR4/6	0.6	6.4	5.4	362
	BC	75-110	10YR5/8	0.2	6.3	5.2	321
	C	110-	10YR6/8	0.1	6.3	5.2	380
2 Flakkebjerg	Ap	0-25	10YR 3/3	1.9	6.5	5.6	535
	AB	25-45	10YR 4/2	0.5	7.1	6.2	250
	E	40-60	2.5Y 5/3	1.0	7.0	6.1	362
	Btg	66-130	10YR 5/4	0.2	8.0	7.2	321
	BC	130-	10YR 4/4	0.2	8.5	7.2	379
3 Borris	Ap	0-25	10YR3/3	2.5	6.7	6.3	910
	Bs	25-40	10YR4/6	0.8	6.5	5.7	736
	BC	40-90	10YR5/8	0.1	5.5	4.4	204
	BC2	66-	10YR5/8	0.1	5.1	4.2	189
4 Mikkeli	Ap	0-25	10YR 3/1	2.8	6.2	5.6	1850
	Bs	27-55	10YR 4/6	0.5	5.9	5.5	1796
	BC	55-90	10YR 6/3	0.1	6.0	5.5	752
	C	90-100	2.5Y 6/2	0.2	6.0	5.5	522
5 Sodankyla	O	0-5	n.d.	42.7	3.7	3.1	
	Ah	5-7	7.5YR2/2	29.2	3.9	3.3	
	E	7-10	7.5YR5/1	3.7	4.2	3.8	
	Bs	10-17	7.5YR4/6	2.1	4.6	4.2	
	BC	17-65	2.5Y4/4	0.6	4.7	4.5	
	C	65-100	2.5Y4/3	0.3	5.3	4.5	
6 Ylistaro	Ap	0-30	7.5YR 2/2	4.6	4.3	3.6	
	Bg	30-52	2.5Y 5/2	1.1	3.9	3.4	
	Bgj1	52-70	2.5Y 5/2	1.0	3.8	3.3	
	[illegible]	70-100	[illegible]	[illegible]	[illegible]	[illegible]	
	BC1	100-125	2.5Y 5/2	1.2	3.4	3.1	
	BC2	125-150	2.5Y 5/2	1.3	3.4	3.2	
7 Jokioinen	Hap	0-35	5YR 2.5/2	28.2	4.9	4.5	
	Ha1	35-59	5YR 2.5/1	22.3	5.1	4.6	
	Ha2	59-80	2.5YR 2.5/1	33.2	5.2	4.6	
	Ha3	80-104	10YR 3/2	18.3	4.7	4.4	
	2Cg	104-135	5Y 5/1	1.7	5.1	4.5	
8 Hole	Ap	0-18	7.5YR 4/3	1.4	6.9	6.3	
	Bw1	18-30	10YR 5/4	0.4	6.5	5.9	
	Bw2	30-54	10YR 5.5/4	0.2	6.0	5.6	
	Cg1	54-72	2.5Y 6/4	0.1	6.6	5.9	
	C1	72-79	10YR 5/3	0.1	6.7	6.1	
	Cg2	79-113	2.5Y 6/2	0.1	6.4	5.7	
	C2	113-130	7.5YR 4/4	0.1	5.7	5.1	
	C3	130-	2.5Y 5/2	0.1	6.0	5.5	
9 Froland	Oe	0-8	2.5YR 2.5/1	n.d.	n.d.	n.d.	
	Oa	8-13	2.5YR 2.5/1	37.8	3.9	2.9	
	Eg	13-20	10YR 5/2	0.9	4.4	3.5	
	Bhs	20-37	5YR 3/1	3.0	4.8	4.0	
	Bsmg	37-63	10YR 4/3	0.9	5.1	4.6	
	Cg	63-89	5Y 5/1	0.6	5.3	5.0	
10 Ås	Ap	0-23	10YR 4/2	2.5	6.2	5.5	
	Eg	23-40	2.5Y 6/2	0.4	6.4	5.6	
	Bt/Eg	40-75	7.5YR 4/2	0.2	6.8	5.8	
	BCt	75-150	5GY 4/1	0.3	6.9	6.0	
11 Kloten	O1	0-2.5	7.5YR 2/2	41.5	4.2	n.d.	
	O2	2.5-5	7.5YR 1.7/1	45.1	3.6		
	Ah	5-6	10YR5/2	17.8	3.6	n.d.	
	E	6-11	10YR8/2	0.6	4.3	n.d.	
	Bhs	11-12	5YR4/4	n.d.	n.d.	n.d.	
	Bs1	12-22	7.5YR5/8	4.9	4.8	n.d.	
	Bs2	22-37	7.5YR5/6	1.6	4.8	n.d.	
	BC	37-49	10YR4/3	0.8	4.9	n.d.	
	C	49-	10YR5/2	0.4	5.0	n.d.	
12 Blomhojden	O1	0-1.5	2.5Y 3/2	17.5	5.2	4.9	
	O2	1.5-3	2.5Y 3/2		4.5	4.0	
	E	3-11	2.5Y 6/2	1.1	5.0	4.1	
	Bs1	11-26	5YR 4/4	4.7	5.2	4.4	
	Bs2	26-51	2.5Y 5/6	1.5	5.6	4.7	
	Cg	51-75	2.5Y 5/4	0.7	5.7	4.7	
13 Lanna	Ap	0-25	10YR 3/3	2.1	6.6	6.0	
	Bg1	25-50	10YR 4/2	0.5	6.5	5.9	
	Bg2	50-72	7.5YR 4/2	0.3	6.8	6.1	
	Bg3	72-92	7.5YR 4/2	0.3	7.1	6.3	
	BCg	92-110	7.5YR 4/2	0.4	7.2	6.4	

Soil	Clay >2µm	Silt 2-63µm	Sand > 63µm	CEC. pH 7.0Cmol/kg*	Base sat. %	Fe-ox mg/kg	Al-ox mg/kg
1 Jyndevad	4	6	90	10.3	n.d.	3520	2280
	4	3	93	9.7	26	3920	5040
	4	3	93	6.5	16	2280	4482
	3	2	95	3.4	23	2280	3000
	2	2	96	3.1	28	1640	2160
2 Flakkebjerg	17	33	50	13.1	68		
	22	36	42	16.9	82		
	19	35	46	13.9	73		
	24	24	52	19.9	91		
	19	27	54	n.d.	n.d.		
3 Borris	6	22	72	12.3	64	4760	2000
	5	28	67	7.6	35	3480	3520
	10	20	71	4.5	33	2200	1600
	14	20	66	6.7	45	4360	1760
4 Mikkeli	5	32	63	12.9	71	3700	4200
	3	33	64	3.7	43	2700	4000
	3	36	61	1.3	46	400	1500
	7	44	49	1.6	44	700	1400
5 Sodankyla	n.d.	n.d.	n.d.	91.0	15	n.d.	n.d.
	n.d.	n.d.	n.d.	54.8	6	n.d.	n.d.
	6	47	47	n.d.	n.d.	2004	1220
	6	48	46	14.6	1	6378	5101
	6	42	52	6.4	3	3710	2919
	13	40	48	7.6	36	5234	1052
6 Ylistaro	24	64	12	19.9	10	10500	3400
	27	64	9	11.8	14	7900	1100
	26	67	7	10.3	13	6100	900
	26	67	7	9.4	17	5700	900
	28	64	8	11.5	17	8500	1000
	26	65	9	11.1	29	7800	1000
7 Jokioinen				138.0 *	20 *		
				125.0 *	20 *		
				141.0 *	21 *		
				86.7	23 *		
	81	18	1	29.7	45 *		
8 Hole	5	46	49	9.5	83		
	4	42	54	3.8	48		
	2	34	64	2.2	32		
	4	42	54	1.8	56		
	6	16	79	2.2	68		
	4	50	46	2.8	61		
	3	1	96	0.9	53		
	2	1	97	0.8	100		
9 Froland				n.d.	n.d.		
				79.5	6		
	3	17	80	3.4	4	300	200
	4	19	77	15.9	1	5300	3900
	3	17	80	3.5	1	3800	3000
	7	29	64	2.9	3		
10 Ås	19	44	37	13.3	64		
	21	63	16	7.4	61		
	29	64	7	9.4	84		
	35	55	10	11.7	87		
11 Kloten	n.d.	n.d.	n.d.	68.4	18	500	780
				114.0	13	940	1210
	n.d.	n.d.	n.d.	46.4	13	640	1140
	n.d.	n.d.	n.d.	3.1	6	80	310
	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	#
	n.d.	n.d.	n.d.	14.8	3	22560	20610
	2	48	50	n.d.	2	17060	21160
	2	48	50	n.d.	3	1930	8340
	4	46	50	n.d.	2	910	1000
12 Blomhojden	9	39	52	28.1	49		
	10	32	58	18.4	12		
13 Lanna	44	48	8	15.0 *	99 *		
	65	33	2	17.9 *	100 *		
	62	36	2	17.1 *	100 *		
	61	37	98	16.8 *	100 *		
	59	40	1	14.6 *	100 *		

groups. The Ylistaro type soils are mineral soils and they do not have fluvic properties or fluvic soil materials which are the characteristics of Fluvisols. Since these soils have been drained for decades, gleyic properties, which are typical for Gleysols, cannot be identified in the upper 50 cm but only at a greater depths. Consequently, these soils have to be classified as Gleyic Cambisols according to FAO and WRB (Table 1). This means that an important soil characteristic such as the sulfuric horizon is not recognised.

The upper depth of the sulfuric horizon and sulfidic material is of major importance for land assessment purposes. The WRB system uses the sulfuric horizon in classification only when it occurs within 100 cm of the soil surface. In the FAO system 125 cm is used, and in Soil Taxonomy 150 cm is used. Deep sulfuric horizons (below 100 cm) will, in the case of artificial drainage, cause environmental hazards, including killing of fish (Hildén & Rapport, 1993). The rigorous criteria of WRB may be justified in tropical acid sulfate soils which are mostly used in rice production. Around the Baltic basin, these soils are commonly drained and deep sulfuric horizons and sulfidic materials must be recognised in the classification.

Proposals for improvement of the WRB

On the basis of the 13 soils/classified and the comparison to the FAO and Soil Taxonomy classification, we propose the following improvements to the WRB system.

Podzolized soils

The uncultivated podzolised reference soils have no problems fulfilling the criteria involving the distribution of oxalate extracted Fe and Al. In many cases they are excluded from, or allowed in the podzol group based on field assessments of the soil colour. In order to incorporate typical Nordic podzols into the Podzol soil group of the WRB, we propose that the WRB adopts the full definition of spodic materials from the Soil Taxonomy, all except for the pH criteria.

Cultivated soils

The Jyndevad, Flakkebjerg, Borris and Mikkeli soils have some of the typical antropogenic features of the Scandinavian agricultural soils. For their classification in the WRB system, we propose:

- Allow a hortic A-horizon in all soil groups.
- Reintroduction of a phosphorous limit (100 ppm Na-HCO_3-P) and a further narrowing of the definition 2000 of the mollic and umbric A-horizon in order to allow many of the agricultural soils to have hortic A-horizons.
- Removal of the pH 5.9 limit in the definition of the spodic horizon.
- Acknowledge hortic as a second level qualifier in all soil groups.

Acid sulfate soils

In order to classify some of the typical Nordic acid sulfate soil in a proper manner, we propose;

- Allowing the Thionic soil unit in both Umbrisol and Cambisol soil groups.
- Sulfuric horizon and sulfidic materials starting betwe-en 100 and 200 cm should be recognised in the Thionic soil unit as Bathithionic (100-200 cm).

Classification according to the WRB including the proposed changes were then tested on the 13 soils (Table 1). After the proposed changes to the WRB, the topsoil characteristics have less influence on the classification at the highest level. Furthermore, the soils with a long cultivation history are segregated at the second level, in the classi fication system.

Conclusions

On the basis of the classification of the 13 typical and widespread Nordic Reference Soils, we evaluated the WRB system against the FAO system and assessed whether or not the WRB classification reflected the most important properties of the 13 soils. The comparison with FAO showed some unfortunate consequences of apparently small changes in the classification system. The pH limit of 5.9 in the Spodic-horizon excludes the intensively cultivated podzolized soils from the podzol soil group. The inclusion of the thin (less than 50 cm) anthropogenic A-horizon within the mollic A-horizon resulted in peculiar classifications of cultivated soils. At present, the WRB classification system cannot be recommended as a land assessment tool in the Nordic countries due to the fact that the names obtained from the present version of the WRB do not always reflect the essential soil characteristics in many of the Nordic soils. Until a revision has been carried out, we recommend that the FAO or the Soil Taxonomy classification system to be used. However, if the proposed changes are taken into account, the WRB soil classification system will perform better than both Soil Taxonomy and FAO. As the WRB is endorsed by IUSS, it is recommended that local experiences with the WRB system be reported to international journals in order to improve future approximations of the WRB system.

Acknowledgments

The authors thank Dr. Lars Krogh of the Institute of Geography, University of Copenhagen for his valuable comments on the manuscript and Dr. Ebba Tiberg for coordinating the Nordic Reference Soils project and Nordic Council of Ministers which were the main sources of funding. Funding was also received from Finnish Ministry of Environment, Danish EPA, National Chemicals Inspectorate, Swedish EPA and Nord-Test. The following persons are also acknowledged for their contribution at different stages of this work: Gerald Kuhnt, Institute of Geography, University of Kiel, Germany; Svend E. Olesen and Tove Heidmann, Danish Institute of Agricultural Sciences; Pekka Hänninen, Raimo Sutinen and Anne-Maj Kähkönen, Geological Survey of Finland; Eivind Solbakken and Ragnhild Sperstad, Norvegian Institute of Land Inventory; Mats Olsson and Pål Andersson, Swedish University of Agricultural Sciences.

References

Breuning-Madsen, H. & Jones, R.J.A. (1995): Soil profile analytical database for the European Union.Danish Journal of Geography 95: 49-57.

Breuning-Madsen, H. and Jensen, N. H. (1996): Soil map of Denmark according to the revised FAO Legend 1990. Danish Journal of Geography 96:51-59.

CEC (1985): Soil map of the European Communities at 1:1000 000. CEC. DG VI. Luxembourg.

Dissing Nielsen, J. & Møberg, J. P. (1984): Klassificering af 5 jordprofiler fra forsøgstationer i Danmark. Tidskrif t for Planteavl 88:155-167.

Dissing Nielsen, J. & Møberg, J. P. (1985): Klassificering af jordprofiler fra forsøgstationer i Danmark. Tidskrift for Planteavl 89:157-168.

Ekström, G. (1953): Åkermarkens matjordstyper. Atlas över Sverige, nr 63-64. Svenska sällskapet för antropologi och geografi. Stockholm.

Eriksson, J., Andersson, A., & Andersson, R. (1997): Current status of Swedish arable soils. Swedish Environmental Protection Ageny Report 4778.

European Soil Bureau (1998): The soil geographical data base of Europe at scale 1:1000 000.

FAO (1974): Soil map of the world at 1:5000 000.Unesco, Paris.

FAO (1988): FAO/Unesco Soil Map of the World. Revised legend, with corrections. World Resources Report 60. FAO, Rome. Reprinted as Technical paper 20. ISRIC, Wageningen, 1994.

FAO (1990): Guidelines for soil profile description. FAO, Rome.

FAO (1995): Topsoil characterization for sustainable land management. Revised draft . FAO, Rome.

FAO (1998): World reference base for soil resources. World Soil Resources Reports 84. FAO, Rome.

Hildén, M. & Rapport, D. (1993): Four centuries of cumulative impacts on a Finnish river and its estuary:an ecosystem health-approach. Journal of Aquatic Ecosystem Health 2: 261-275.

Heineke, H.J., Eckelmann, W., Thomasson, A.J., Jones, R. J.A., Montanarella, L. & Buckley, B. (Ed.) (1998): Land information systems. Developments for planning the sustainable use of land resources. EUR 17729 EN. European Soil Bureau. Joint Research Centre, Ispra, Italy.

Kähäri, J., Mäntylahti, V. & Rannikko, M. (1987): Suomen peltojen viljavuus 1981-1985. Summary: Soil fertility of Finnish cultivated soils in 1981-1985. Viljavu-uspalvelu Oy. Helsinki.

Kuhnt, G. & Muntau, H. (eds) (1994): EURO-Soils-Identification, Collection, Treatment, Characterisation, Special Publication No. 1.94.60, Joint Research Centre, European Commission.

Krogh, L. & Greve, M.H. (1999):Evaluation of World Referece Base for Soil Resources and FAO Map of the World using Nation-wide Grid Soil Data From Denmark. Soil Use and Management 15: 157-166.

Larsen, P.A. (1978): Initial development (ripening) of some reclaimed gyttja soils in Kolindsund, Denmark. Catena 5: 285-304.

Lintinen, P. (1995): Origin and physical characteristics of till fines in Finland. Geological Survey of Finland. Bulletin 379.

McKeague, J.A. & Day, J.H. (1966): Dithionite- and oxalate-extractable Fe and Al as aids in differerentiating various classes of soils. Canadian journal of Soil Science 46: 13-22.

Munsell Soil Color Charts (1994). Kollmorgen Instruments Coperation, New Winsor, NY.

Öborn, I. (1989): Properties and classification of some acid sulphate soils in Sweden. Geoderma 45: 197-219.

Öborn, I. (1994): Morphology, Chemistry, Mineralogy anf Fertility of Some Acid Sulfate Soils in Sweden. Department of Soil Sciences. Reports and Dissertations 18. Swedish University of Agricultural Sciences, Uppsala.

Purokoski, P. (1959): Rannikkoseudun rikkipitoisista maista. Referat. Über die Schwefelhaltigen Böden an der Küste Finnlands. Agricultural Research Centre of Finland. Agrogeological Publications 74. Helsinki.

Rasmussen, K., Sippola, J., Låg, J. and Troedsson, T.(1989): Soil map of Denmark, Finland, Norway and Sweden. Scale 1: 2 000 000. Landbrugsforlaget. Oslo, Norway.

Soil Survey Staff (1998): Keys to Soil Taxonomy, Eighth Ed. Washington D.C., USA.

Spaargaren, O.C. (1994): World Reference Base for Soil Resources. Draft. International Society of Soil Science, International Soil Reference and Information Centre, FAO. Wageningen/Rome.

Statistics Sweden (1993): Yearbook of Agricultural Statistics 1993. Official Statistics of Sweden, Statistics Sweden, Örebro.

Thomas, G.W. (1982): Exchangeable cations. In: Page, A. L. et al. (eds.). Methods of Soil Analysis. Chemical and Microbiological Properties. American Society of Agronomy. Agronomy 9: 159-164.

Tiberg, E. (Ed.), Greve, M.H., Helweg, A., Yli-Halla, M., Eklo, O.M., Nyborg, Å.A., Solbakken, E., Öborn, I. & Stenström, J. (1998): Nordic reference soils. 1. Characterisation and classification of 13 typical nordic soils. 2. Sorption of 2,4-D, atrazine and glyphosate. TemaNord 537.

Urvas, L. (1995): Viljelymaan ravinne- ja raskasmetallipitoisuuksien seuranta. Summary: Monitoring nutrient and heavy-metal concentrations in cultivated land. Agricultural Research Centre of Finland. Research report 15/95. Jokioinen, Finland.

Van Reeuwijk, L.P.(1995): Procedures for soil analysis. International Soil Reference and Information Centre. Technical Paper 9.

Yli-Halla, M., (1987): Sulphate sorption by Finnish mineral soils. Journal of Agricultural Science in Finland 59: 41-46.

Yli-Halla, M., (1997): Classification of acid sulphate soils of Finland according to Soil Taxonomy and the FAO/Unesco legend. Agricultural and Food Science in Finland 6: 247-258.

Yli-Halla, M., Puustinen, M. & Koskiaho, J.(1999): Area of cultivated acid sulfate soils in Finland. Soil Use and Management 15: 62-67.

Acknowledgments

The authors thank Dr. Lars Krogh of the Institute of Geography, University of Copenhagen for his valuable comments on the manuscript and Dr. Ebba Tiberg for coordinating the Nordic Reference Soils project and Nordic Council of Ministers which were the main sources of funding. Funding was also received from Finnish Ministry of Environment, Danish EPA, National Chemicals Inspectorate, Swedish EPA and Nord-Test. The following persons are also acknowledged for their contribution at different stages of this work: Gerald Kuhnt, Institute of Geography, University of Kiel, Germany; Svend E. Olesen and Tove Heidmann, Danish Institute of Agricultural Sciences; Pekka Hänninen, Raimo Sutinen and Anne-Maj Kähkönen, Geological Survey of Finland; Eivind Solbakken and Ragnhild Sperstad, Norvegian Institute of Land Inventory; Mats Olsson and Pål Andersson, Swedish University of Agricultural Sciences.

References

Breuning-Madsen, H. & Jones, R.J.A. (1995): Soil profile analytical database for the European Union.Danish Journal of Geography 95: 49-57.

Breuning-Madsen, H. and Jensen, N. H. (1996): Soil map of Denmark according to the revised FAO Legend 1990. Danish Journal of Geography 96:51-59.

CEC (1985): Soil map of the European Communities at 1:1000 000. CEC. DG VI. Luxembourg.

Dissing Nielsen, J. & Møberg, J. P. (1984): Klassificering af 5 jordprofiler fra forsøgstationer i Danmark. Tidskrif t for Planteavl 88:155-167.

Dissing Nielsen, J. & Møberg, J. P. (1985): Klassificering af jordprofiler fra forsøgstationer i Danmark. Tidskrift for Planteavl 89:157-168.

Ekström, G. (1953): Åkermarkens matjordstyper. Atlas över Sverige, nr 63-64. Svenska sällskapet för antropologi och geografi. Stockholm.

Eriksson, J., Andersson, A., & Andersson, R. (1997): Current status of Swedish arable soils. Swedish Environmental Protection Ageny Report 4778.

European Soil Bureau (1998): The soil geographical data base of Europe at scale 1:1000 000.

FAO (1974): Soil map of the world at 1:5000 000.Unesco, Paris.

FAO (1988): FAO/Unesco Soil Map of the World. Revised legend, with corrections. World Resources Report 60. FAO, Rome. Reprinted as Technical paper 20. ISRIC, Wageningen, 1994.

FAO (1990): Guidelines for soil profile description. FAO, Rome.

FAO (1995): Topsoil characterization for sustainable land management. Revised draft . FAO, Rome.

FAO (1998): World reference base for soil resources. World Soil Resources Reports 84. FAO, Rome.

Hildén, M. & Rapport, D. (1993): Four centuries of cumulative impacts on a Finnish river and its estuary:an ecosystem health-approach. Journal of Aquatic Ecosystem Health 2: 261-275.

Heineke, H.J., Eckelmann, W., Thomasson, A.J., Jones, R. J.A., Montanarella, L. & Buckley, B. (Ed.) (1998): Land information systems. Developments for planning the sustainable use of land resources. EUR 17729 EN. European Soil Bureau. Joint Research Centre, Ispra, Italy.

Kähäri, J., Mäntylahti, V. & Rannikko, M. (1987): Suomen peltojen viljavuus 1981-1985. Summary: Soil fertility of Finnish cultivated soils in 1981-1985. Viljavu-uspalvelu Oy. Helsinki.

Kuhnt, G. & Muntau, H. (eds) (1994): EURO-Soils-Identification, Collection, Treatment, Characterisation, Special Publication No. 1.94.60, Joint Research Centre, European Commission.

Krogh, L. & Greve, M.H. (1999):Evaluation of World Referece Base for Soil Resources and FAO Map of the World using Nation-wide Grid Soil Data From Denmark. Soil Use and Management 15: 157-166.

Larsen, P.A. (1978): Initial development (ripening) of some reclaimed gyttja soils in Kolindsund, Denmark. Catena 5: 285-304.

Lintinen, P. (1995): Origin and physical characteristics of till fines in Finland. Geological Survey of Finland. Bulletin 379.

McKeague, J.A. & Day, J.H. (1966): Dithionite- and oxalate-extractable Fe and Al as aids in differerentiating various classes of soils. Canadian journal of Soil Science 46: 13-22.

Munsell Soil Color Charts (1994). Kollmorgen Instruments Coperation, New Winsor, NY.

Öborn, I. (1989): Properties and classification of some acid sulphate soils in Sweden. Geoderma 45: 197-219.

Öborn, I. (1994): Morphology, Chemistry, Mineralogy anf Fertility of Some Acid Sulfate Soils in Sweden. Department of Soil Sciences. Reports and Dissertations 18. Swedish University of Agricultural Sciences, Uppsala.