Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning

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ABSTRACT

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One way of addressing the paucity of soil hydraulic data for simulation modeling is through the use of pedotransfer functions. In this case soils data routinely collected during systematic soil surveys are used to predict the soil hydraulic characteristics. To derive pedotransfer functions for European soils 18 institutions in 10 EU countries participated in the establishment of a HYPRES database. The first task was to develop a flexible database structure. Next, the database was filled with measured hydraulic characteristics. Finally, the stored data were used for the derivation of class and continuous pedotransfer functions. Class pedotransfer functions were derived for 11 major building blocks. These functions and the Soil Geographical Data Base of Europe were combined for the generation of a map on the water availability of a map on the water availability of European soils.

Keywords: pedotransfer function, texture class, soil physics, computer simulation

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Contents

Preface

The presented study was funded by the European Commission under the Human Capital and Mobility (DG XII) program. The project started at the beginning of 1995 and was completed in early 1998. The project team responsible for the overall execution of the project consisted of researchers from:

- The Winand Staring Centre — project co-ordinator
- Macaulay Land Use Research Institute — project researcher
- The Winand Staring Centre — research student
- INRA, Orléans — GIS specialist

Co-ordination of network activities, construction and maintenance of the database was concentrated at the Winand Staring Centre in Wageningen, the Netherlands. Relatively short visits at task level from Wageningen to the institutions were sufficient to guarantee a satisfactory scientific co-operation. In total 4 meetings of the team leaders of all collaborating institutions were organised:

- Preparatory Workshop in 1994 at the Winand Staring Centre, Wageningen, the Netherlands.
- First Annual Meeting in 1995 at the Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany.
- Second Annual Meeting in 1996 at the Institut National de la Recherche Agronomique, Science du Sol, Orléans, France.
- Third Annual Meeting in 1997 at the Istituto di Idraulica Agraria, Universita' degli Studi di Napoli 'Federico II', Naples, Italy.

At the 1996 Annual Meeting in Orléans the project was accepted as the fourth working group of the European Soil Bureau (ESB). This Bureau is responsible for the co-ordination of information on soil data within the European Union. Throughout the project contacts were maintained with scientists at the US Salinity Laboratory in Riverside, California, USA, as they were working on a comparable, world wide database of measured soil hydraulic parameters.

The establishment of a database of measured soil hydraulic characteristics of European soils is a first contribution to meeting the lack of hydraulic input data for simulation models. As a database is never complete, this version of the HYPRES database holds what is presently collected and analysed. When more data become available, updates of the derived pedotransfer functions will be required. Pedotransfer functions are useful tools for predicting soil hydraulic characteristics. However, they can not always replace direct measurements. Depending on the intended use it will have to be decided whether can be relayed on the more general pedotransfer functions or whether specific, direct measurements are required.

Summary

The quality of the European soils and water are deteriorating due to the intensive agricultural and industrial activities in many regions of Europe. Scientists have developed complex computer models to simulate water and solute movement in the unsaturated zone in order to control and ultimately rectify this damage. A major obstacle for applying these models is the lack of easy accessible and representative soil hydraulic properties. As a consequence, there was a need to bring together the available hydraulic properties measured by different institutions in Europe in to one central database. Analysis of the information gathered in such a database resulted in a set of pedotransfer functions applicable on a European scale. Pedotransfer functions predict the hydraulic properties from parameters collected in soil survey and can be a good alternative for costly and time-consuming direct measurement.

A total of 18 institutions from 10 EU member states officially collaborated in establishing the database of soil hydraulic properties of European soils known as HYPRES. This database has a flexible relational structure capable of holding a wide diversity of both soil hydraulic and pedological data needed to derive pedotransfer functions. As these data were derived from numerous sources it was necessary to standardise both particle size and the raw hydraulic properties data. The latter were standardised by fitting the Mualem-van Genuchten model parameters to the individual $\theta(h)$ and $K(h)$ hydraulic characteristics stored in HYPRES. The HYPRES database contains information on in total 5521 soil horizons. Of these, 397 had insufficient textural information available in order to classify them. Of the remaining 5124 horizons 4030 could be processed using the Mualem-van Genuchten parameterisation scheme. A total of 1136 horizons had information on both water retention and hydraulic conductivity and 2894 horizons had only information on water retention and not on hydraulic conductivity.

By combining the 5 FAO texture classes of the European soil map with a distinction being made between topsoils and subsoils and the inclusion of organic layers, 11 texture classes were defined for the classification of the available data. Next, both class and continuous pedotransfer functions were developed which predict the hydraulic properties based on soil survey information. By using the class pedotransfer functions in combination with the 1 : 1 000 000 scale Soil Geographical Data Base of Europe, new information was generated in the form of a map showing the water availability of European soils.

A list of references of articles on pedotransfer functions is added as well as information on HYPRES that can be found on the World Wide Web. A number of conclusions and recommendations are made regarding the project which are summarised in the following.

The HYPRES database constitutes a unique source of information on soil hydraulic characteristics of European soils. Continuing creative and innovative use of this

information (e.g. neural networks, other types of correlation, linkage with other European databases) might produce even more useful new information.

Working in a network structure during this project proved to be very useful. The mutual contacts stimulated the exchange of ideas and methods. This increased uniformity in approaches and measurement techniques amongst the partners and contributed to a more compatible structure of national databases. It is expected that the end products of this in-depth investment will be used by many researchers working on European agricultural and environmental issues.

Both class and continuous pedotransfer functions are derived. Class pedotransfer functions give the mean hydraulic characteristics for rather broadly defined soil texture classes. As a consequence, these functions are generally applicable, but they give limited site specific information. In contrast, continuous pedotransfer functions are more site specific as they use site specific information. However, their general applicability is limited.

By making use of the 11 texture classes of the 1 : 1 000 000 scale Soil Geographical Data Base of Europe, the derived pedotransfer functions can be applied on a national scale of 1 : 1 000 000 or more general. For more detailed applications it is necessary to measure the hydraulic characteristics of the profile at a particular location.

The HYPRES database and its derived pedotransfer functions make it possible to assign soil hydraulic characteristics to soils with a textural composition comparable to the soils for which these pedotransfer functions have been derived. However, the functions should not be used for the assignment of hydraulic characteristics to soils outside Europe. In the first case, an acceptable form of data interpolation is carried out, whereas in the second case a very risky form of data extrapolation is applied.

It is recommended that periodic updates of the pedotransfer functions be made when more data become available. The ongoing process of adding new data and updating will result in improvement of the end products and will increase the applicability of the end products for Europe as a whole.

The European Soil Bureau (ESB) acted as an excellent stimulator as it brings together European soil scientists working in different disciplines. Their functioning stimulated the exchange between different working groups and thereby stimulated the generation of new information.

1 Introduction

1.1 Background of the project

Simulation models have become indispensable tools in research which aims to quantify and to integrate the most important physical, chemical and biological processes active in the unsaturated zone of agricultural soils. Use of these models on a European scale has shown that many input data have to be quantified in order to be able to make reliable predictions. However, these data are usually fragmented, of varying degrees of detail and reliability and are held in different institutions scattered throughout Europe. In various fields of model application like hydrology, environmental risk analysis or global change assessment, the lack of accurate parameters on soil hydraulics is considered to be a major obstacle to progress. The soil hydraulic properties of water retention and hydraulic conductivity curves are key parameters in this respect. Despite many efforts in developing new measurement techniques, the unfortunate fact remains that these hydraulic properties are still notoriously difficult to measure, especially for undisturbed field soils. An attractive alternative to direct measurement is the estimation of hydraulic properties by pedotransfer functions. Pedotransfer functions relate hydraulic properties to more easily measured soil data such as soil texture, organic matter content and/or other data routinely measured in soil surveys. A prerequisite for deriving pedotransfer functions which can be applied at a European scale, is the availability of a database holding information on basic soil data and on soil hydraulic parameters for a wide range of soils across Europe.

Thus, there was a perceived need to have a concerted action to bring together the available measured hydraulic properties held by different institutions in Europe into one central database. Analysis of the information gathered in such a database would result in a set of pedotransfer functions applicable to the whole European Union. As a first preparatory step, a survey of interest was carried out among 26 institutions in Europe to investigate their willingness to co-operate in such a concerted action. The institutions were asked if they had measured soil hydraulic characteristics available for their country, if they saw the need for the establishment of a database of measured soil hydraulic characteristics and if they would be interested in participating in such a project. Summarising the responses, it was clear that, quite often, measured hydraulic characteristics were available to some degree, that all would be willing to participate if possible, and that they would be willing to contribute their data to a central database. These enthusiastic responses stressed the importance of initiating a collaborative effort.

An operation like this can only succeed if all participating institutions in the network are convinced of the need to establish such a database and if they have a clear picture of how this goal will be achieved. As a preparatory action towards the establishment of the network, a workshop was organised at the Winand Staring Centre in Wageningen on 14 and 15 April 1994. The aim of this workshop, in which representatives of 26 institutions participated, was to discuss the conceptual and practical aspects of the approach more thoroughly. The workshop resulted in a more precise project proposal, which was subsequently submitted for funding by the European Commission under the Human Capital and Mobility (DG XII) program. Unfortunately only EU member states could receive funds from the HCM program. As a consequence, only 18 institutions from 10 EU member states were officially included in the proposal while 8 institutions from Central and Eastern Europe could not participate under the EU funding rules.

The project was granted funding (CHRX-CT94-0639) and started for a period of 3 years on 1 January 1995 under the title '*Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning*'. The proposal aimed explicitly at integrating hydraulic parameters available in the different national institutions into a central database for Europe and to use these data to derive pedotransfer functions by relating soil survey data to soil hydraulic data. The database would also be an unique source of information on an European scale and be useful for scientists working in agriculture, environment and nature preservation as it provides those soil hydraulic data which are currently lacking and which are necessary for the application of simulation models at national and regional scales on global change and sustainable agriculture.

The proposed project methodology was such that the institutions in the different European countries made an inventory of their existing measured soil hydraulic parameters. After screening of these available data by the institutions, it was processed and stored in a central database together with information routinely gathered during soil surveys such as the percentages clay, silt, sand and organic matter of the soil horizons for which the hydraulic properties were measured. Also, horizon nomenclature (FAO, 1990) and taxonomic classifications were to be included (CEC, 1985; FAO/UNESCO 1994). Soil horizons were grouped according to their pedology, their texture, their organic matter content or their dry bulk density similar to those soil horizons held within the 1 : 1 000 000 scale Soil Geographical Data Base of Europe (Jamagne et al., 1994). This was done in co-operation with the working group of the European Soil Bureau (ESB) on 'Soil geographical database of Europe'.

Next the individually measured soil moisture retention and hydraulic conductivity curves were parameterised using the equations proposed by van Genuchten (1980). After classifying the soil hydraulic characteristics in 11 defined soil texture classes, the average characteristics for each class was calculated. These average characteristics were called class pedotransfer functions. Correlation between the Mualem-van Genuchten parameters and data gathered in soil surveys (for example, percentage clay, silt) were determined, resulting in the establishment of continuous pedotransfer functions. These pedotransfer functions allow more refined estimates of the hydraulic properties to be made for a different range of textural classes.

In the operation of the network, scientist from the participating institutions were involved in a broad spectrum of concepts, theories, data analysis and measurement techniques. Therefore, participation in the network was a constant, mutual learning exercise for the scientists involved, which will, in turn, have positive benefits for the institutions of participating scientists. There are considerable scientific as well as the practical benefits of being co-owners of the database and, by looking beyond national borders, the scientists awareness of the importance of standardisation of measurement and data analysis techniques has been increased. It also revealed that theories and concepts which were developed for a national scale prove to be valuable on a much broader European scale, eventually leading to a situation in which European institutions act in a more complementary way

During the first year of the project (1995), the emphasis was on developing a flexible database structure capable of holding a wide diversity of data related to measured soil hydraulic properties. This database is known as HYPRES: HYdraulic PRoperties of European Soils. The structure of HYPRES is described in Chapter 2. The second year of the project (1996) was largely devoted to collating the data from the project partners across the whole of Europe and entering these data in HYPRES. At the same time a start was made with pre-processing the data. This included standardisation of particle size classes and parameterisation of the hydraulic characteristics with the Mualem-van Genuchten equations. This work is described in Chapter 3. The last year of the project (1997) was devoted to the completion of the data standardisation and to the subsequent development of both class and continuous pedotransfer functions. A practical use of HYPRES was also demonstrated by the linkage of this database with the 1 : 1 000 000 scale Soil Geographical Data Base of Europe. This work is described in the Chapters 4 and 5 respectively. Finally, Chapter 6 of this report lists the conclusions and recommendations.

1.2 Institutions participating in the project

In total 18 institutions in 10 EU countries officially participated in the project (Fig. 1). The names of these institutions, their locations and the team leaders representing the institutions are listed below.

1. The Winand Staring Centre for Integrated Land Soil and Water Research
   Wageningen, the Netherlands
   Dr. J.H.M. Wösten

2. Wageningen Agricultural University, Dept. of Soil Science and Geology
   Wageningen, the Netherlands
   Dr. H.W.G. Booltink

3. Consejo Superior de Investigaciones Cientificas, Instituto de Recursos
   Naturales y Agrobiologia de Sevilla
   Sevilla, Spain
   Dr. F. Moreno

4. Institut National de la Recherche Agronomique - Science du Sol
   Orléans, France
   Dr. A. Bruand

5. Institut National de la Recherche Agronomique - Science du Sol
Montpellier, France
Dr. M. Voltz

6. Soil Survey and Land Research Centre
Silsoe, England
Dr. J. Hollis

7. Macaulay Land Use Research Institute
Aberdeen, Scotland
Dr. A. Lilly

8. The Danish Institute of Plant and Soil Science, Department of Land Use
Tjele, Denmark
Dr. S. Olesen

9. Istituto di Idraulica Agraria Universita' degli Studi di Napoli 'Federico II'
Napoli, Italy
Dr. N. Romano

10. Technische Universität Berlin, Institut für Ecology, Department of Soil Science
Berlin, Germany
Dr. R. Plagge

11. Technische Universität Braunschweig, Institut für Geographie und Geoökologie
Braunschweig, Germany
Dr. B. Diekkrüger

12. GSF - Forschungszentrum für Umwelt und Gesundheit, Institut für Bodenökologie
Oberschleissheim, Germany
Dr. E. Priesack

13. Zentrum für Agrarlandschafts- und Landnutzungsforschung (ZALF) e.V., Institut für Hydrologie
Müncheberg, Germany
Dr. U. Schindler

14. Bundesanstalt für Geowissenschaften und Rohstoffe
Hannover, Germany
Dr. V. Hennings

15. Aristotle University of Thessaloniki, Soil Science Laboratory
Thessaloniki, Greece
Dr. K.P. Panayiotopoulos

16. Agricultural University of Athens, Laboratory of Soils and Agricultural Chemistry
Athens, Greece
Dr. C. Kosmas

17. Estação Agronómica Nacional
Lisboa, Portugal
Dr. M. da Conceição Goncalves

18. Katholieke Universiteit Leuven, Institute for Land and Water Management
Leuven, Belgium
Dr. L Hubrechts

In addition, three further Institutions played an active part in contributing data and in scientific discussions during the three years of the project, these are:

a. Swedish University of Agricultural Sciences, Department of Soil Sciences
Uppsala, Sweden
Dr. N. J. Jarvis

b. Department of Agriculture, Northern Ireland
Belfast, Northern Ireland
Dr. A.J. Higgins

c. Soil Fertility Research Institute
Bratislava, Slovakia
Dr. B. Houšková

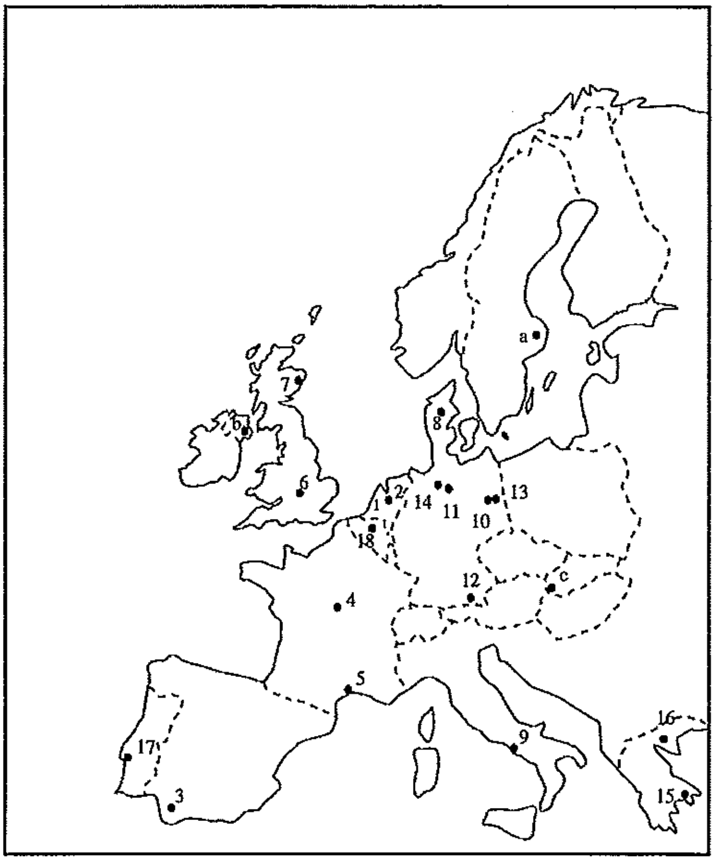


Fig. 1 Location of the network institutions across Europe: the numbers refer to the list of Institutions shown above

1.3 Organisation of the network

For practical reasons, co-ordination of network activities, construction and maintenance of the database was concentrated at the Winand Staring Centre in Wageningen, the Netherlands. Since the proposed network requires the co-operation of 18 European institutions, considerable attention has been paid to efficient interaction between these institutions. Current computer linking capabilities allowed for productive co-operation on common science issues without necessarily requiring extended presence of scientists at the same physical location. Relatively short visits at task level from Wageningen by the Project Co-ordinator and Project Researcher to the institutions was sufficient to guarantee a satisfactory scientific co-operation. Besides these visits at task level, three yearly network meetings were organised where team leaders of all collaborating institutions met. These meetings took place at one of the participating institutions and ensured sufficient integration within the network. Throughout the project contacts were maintained with scientists at the US Salinity Laboratory in Riverside, California, USA, as they were working on the establishment of a comparable, world wide database of measured soil hydraulic parameters.

The project team responsible for the overall execution of the project consisted of the following persons:

Henk Wösten	The Winand Staring Centre	Project Co-ordinator
Allan Lilly	Macaulay Land Use Research Institute	Project Researcher
Attila Nemes	The Winand Staring Centre	Research Student
Christine Le Bas	INRA, Orléans	GIS Specialist

The following 4 meetings of the team leaders of all collaborating institutions were organised:

1 Preparatory Workshop	14-15 April 1994	The Winand Staring Centre Wageningen, the Netherlands
2 First Annual Meeting	19-21 October 1995	Bundesanstalt für Geowissenschaftenund Rohstoffe Hannover, Germany
3 Second Annual Meeting	10-12 October 1996	Institut National de la Recherche Agronomique - Science du Sol Orléans, France
4 Third Annual Meeting	2-4 October 1997	Istituto di Idraulica Agraria Universita' degli Studi di Napoli 'Federico II' Naples, Italy

The European Soil Bureau (ESB) was established in 1996 at the Joint Research Centre in Ispra, Italy and is responsible for the co-ordination of information on soil data within the European Union. At the 1996 Annual Meeting in Orléans, the invitation to have our project adopted as the fourth working group of the ESB was accepted. This means that the final version of the HYPRES database will be managed and distributed through the ESB according to the data license agreement procedure as formulated by the 'Information Access working group' of the ESB.

2 The Structure of the HYPRES database (HYdraulic PRoperties of European Soils

2.1 Introduction

The development of the HYPRES database (HYdraulic PRoperties of European Soils) was not an end in itself but rather a means of storing and manipulating the data needed to derive the pedotransfer functions and as an inventory of the existing soil hydraulic data in the European Union. However, it was soon realised that HYPRES would become one of the main products of the project along with the pedotransfer functions. Its data would be in demand from a wide range of users for future soil, environment and climate research within Europe. As there was great diversity in the data being collected and manipulated, it was important to have a database with a relational structure which allowed flexibility in data extraction, for example, using a variety of fields or by a combination of fields. Therefore HYPRES was developed within the Oracle Relational Database Management System™ . As Oracle uses SQL as its query language, it compatible with many other database systems. The desire to have compatibility with existing EU-wide soils databases led directly to the selection of the key identifying parameters used throughout HYPRES as well as many of the attributes stored.

2.2 Brief description of the structure

The HYPRES database comprises six separate tables (Fig. 2 and Appendix 1) each of which uses a geo-reference (Oracle field *gridref*) as the primary key and, where appropriate, also the horizon notation (*horizon*) as the secondary key. The attributes stored in each table closely resemble those stored in the UNSODA database (Leij et al., 1994) as these attributes were deemed by the delegates at an International workshop to be the most important for improving existing parametric and physico-empirical models and for deriving new pedotransfer functions (van Genuchten et al., 1992). However, the additional attributes needed to link with existing EU databases were also collected. These and the other data will be described in detail in Chapter 2, Section 4.

The BASICDATA table (Appendix 2) contains the 'descriptor' data, for example, information on the soil type, where the soil profile was located and a description of the site and other environmental conditions. The unique primary key field is *gridref*, which is used both as a unique identifier and to ensure that referential integrity is maintained within the subsequent tables so that all data can be related to these descriptor data. This field also provides a link between the database and other European soil datasets and allows the data to be related to other spatially referenced geo-physical factors such as climate or land use.

The five remaining tables are linked by both the geo-reference and the horizon notation as each soil profile generally contains more than one sampled horizon. The horizon notation follow the FAO system (FAO, 1990) and is formatted according to a set of rules in order to simplify the selection of data and to allow greater refinement in this selection process. As the *horizon* field is a key identifying attribute which links tables, it follows that there must also be a unique combination of *gridref* and *horizon* for each sample in the database. Where the horizon was sampled in replicate, an additional alphabetic character was appended to the horizon notation (see the detailed description of the SOIL_PROPS table, Chapter 2, Section 4).

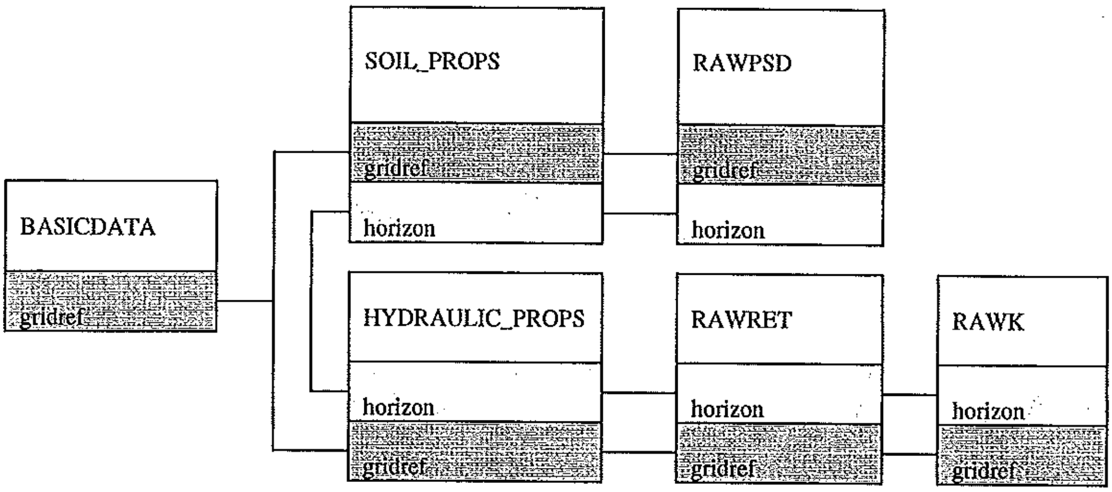


Fig. 2 Structure of the HYPRES database showing the six separate tables

The table SOIL_PROPS (Appendix 2) stores most of the data essential to the derivation of pedotransfer functions such as particle size class, organic matter contents and bulk densities as well as additional pedological information. The HYDRAULIC_PROPS table (Appendix 2) holds only derived or standardised data such as the Mualem-van Genuchten parameters (van Genuchten et al., 1991) and calculated soil moisture retention and hydraulic conductivities at 14 pre-determined pressure heads (see Chapter 3). The 'RAW' tables, that is RAWRET, RAWK and RAWPSD (Appendix 2), store the data on moisture retention, conductivity and particle size distributions, which were contributed by the network partners and is in its 'raw' state, that is, prior to any standardisation. The RAWRET and RAWK tables are very large, containing numerous pairs of data which are not readily usable, however, it is important to continue to store these 'raw' data for a variety of reasons, for example, if new or improved parameterisation methods become available or for testing and comparing novel methods of analysis.

2.3 HYPRES Version 1.0

HYPRES Version 1.0 comprises data from 18 Institutions in 11 EU member states. It has around 25 megabytes of data held in six separate data tables and represents 95 different soil types according to the modified FAO soil legend (CEC, 1985). There are 1777 sampled locations with 5521 samples (including replicates) from 4486 soil horizons (Tables 1 and 2). The RAWRET and RAWK tables have over 197 000 $\theta(h)$ and about 120 500 $K(h)$ data pairs respectively. It is difficult to validate all the data in a database the size of HYPRES, but simple checks were carried out prior to loading the data in to the main database, for example, time was taken to clarify descriptions of methodology, to ensure as many fields as possible had data entered, and that the data values were within expected limits. After all the data were loaded, checks were made to ensure the uniqueness of the geo-referencing and the geo-reference/horizon combinations so that all sets of data in any table could be related to data in either the BASICDATA or SOIL_PROPS tables (only these two had a complete set of profile or horizon based data).

Table 1 Summary of statistics of data within HYPRES

Soil units	95
Soil profiles	1777
Soil samples (including replicates)	5521
Soil horizons (excluding replicates)	4486
Used in class pedotransfer	4030

Table 2 Number of profiles per Major Soil Group:

Cambisols	512
Fluvisols	421
Gleysols	209
Luvisols	186
Podzols	158
Phaeozems	53
Histosols	30

2.4 Description of database attributes

2.4.1 BASICDATA Table

This table stores pedological and environmental data as well as textual descriptions of the methods of analyses. Information is also held on the source of the data (for example, contact names and addresses) which allows users to obtain further pedological data if required.

gridref: geo-reference to 1 m resolution using a European standard system

The *gridref* was generated by the retrospective conversion of the national geo-references. This was necessary as many different geo-referencing systems are in use throughout Europe and, before the data could be manipulation within EU-wide Geographic Information Systems (GIS), they had to be converted to a common system. This system uses the Lambert Azimuthal projection and allows a resolution to within 1 m enabling this field also to function as one of the unique identifiers. Other international systems such as latitude and longitude gave a poor resolution and one which varied depending on location, therefore, it was not possible to have an adequate distinction between closely sited profiles.

name: profile name to allow reference to a soil profile description

The *name* field provides a potential method of cross referencing with any existing profile descriptions which may be held in other databases and provides a shorthand method of referring to individual sample locations where given. Normally the names are from the locality where the soil was sampled, for example, a research station or farm.

FAO_soil: FAO soil unit code modified for Europe

To allow linkages to be made with the 1: 1 000 000 scale Soil Geographical Data Base of Europe (Jamagne et al., 1994) each soil sampled was named according to the modified FAO soil legend at the soil unit level wherever possible (CEC, 1985). Some profiles are also classified in the revised FAO/UNESCO soil map legend format (1994) and in a few cases, it was not possible to assign a FAO soil type.

country: numeric code for each country

The numeric code used for each country from which data were received is compatible with other EU-wide soil datasets and were allocated as follows:

30	Greece	31	Netherlands	32	Belgium
33	France	34	Spain	39	Italy
42	Slovakia	45	Denmark	46	Sweden
49	Germany	351	Portugal	440	England/Wales
441	Scotland	442	Northern Ireland		

localngr: geo-reference using a national system

This field has the geo-reference of the sample location as recorded in the country of origin and, in general, is given to a resolution of 1 m. However, in some cases, only approximate geo-references were supplied, for example, to within 50 m. Wherever possible, the geo-references were converted to the European standard system retrospectively and stored within the *gridref* field but, by retaining the original geo-reference, a link with profile descriptions held in other, national databases is still retained.

local_soil: soil type using an indigenous classification

The local soil type in the taxonomy used in each country or region of origin where this information is available. Again this preserves a link with any existing soil profile database.

localseries: soil series name of the soil

The name of the soil series (where used or where appropriate) in the naming convention used in each individual country.

top_depth_gw: upper boundary of the groundwater table

The typical depth (cm) below the soil surface to the maximum height attained by a ground watertable. For example, if the watertable regularly rises to within 40 cm of the soil surface then 40 will appear in this field. If not applicable, that is, there is no groundwater table then NA was recorded. If a groundwater table was present (or likely to be present) but the depth was not determined, ND was recorded. The depth to groundwater can be an important factor in land suitability assessments particularly as plants and crops will have access to water sources other than vadose zone pore water.

***bot_depth_gw**: lower boundary of the groundwater table*

The typical minimum level of the ground watertable below the soil surface (cm), for example, if it retreats to 130 cm below the soil surface in summer then 130 will be recorded. If not applicable, that is, there is no groundwater table then NA was recorded (not applicable). If a groundwater table was present but the depth was not determined then ND was recorded (not determined).

***sitedescrip**: description of the sample site*

Textual descriptions of the sample location or any other relevant information, for example, the land use, the geography, the weather prior to sampling.

***sampledate**: date when the sample was taken*

This is the date that the soil was sampled, not when the laboratory determination was done. This distinction is important particularly as the hydraulic properties are known to vary significantly with seasonal changes. This field will be blank if the sample date is not known. All dates are year 2000 compliant.

***annrain**: long term average annual rainfall of the locality (mm)*

The average annual rainfall (mm) gives a general indication of the long term climatic conditions pertaining to the site and was generally taken from climate records. This attribute was not available for all datasets and remains within HYPRES in order to retain compatibility with the UNSODA, However, since the HYPRES data are largely geo-referenced then it is of more relevance to combine these soil hydraulic data with climate data within a Geographic Information System where more sophisticated climate parameters can be used more effectively. Where no rainfall data are available then ND was recorded.

***ave_jan_temp**: long term average annual January temperature (°C)*

The long term average January temperature in degrees Celsius taken from climate records. Again this field was retained in order to remain compatible with the UNSODA database and allows an assessment of the climatic conditions of the site. If this attribute has not been determined then ND was recorded.

ave_jul_temp: long term average annual July temperature (^oC)

The long term average July temperature in degrees Celsius also taken from climate records. Again this field was retained in order to remain compatible with the UNSODA database and allows an assessment of the climatic conditions of the site. If this attribute has not been determined then ND was recorded.

contact_name: a contact to obtain more information

The name of the person who contributed the data and who has some knowledge of the data.

contact_address: contact address

The address and affiliation of the data contributor.

email: email address

Email address for rapid contact.

publicn: any relevant publication

Any relevant references where the data or methodologies have been published. It may have been necessary to abbreviate the list. If there is no information for this attribute, then ND was recorded.

comments1: comments on methodology, site, reasons for sampling, related profiles

Free text of up to 255 characters to describe what analyses were done on the samples (for example, laboratory water release, field saturated hydraulic conductivity), reasons for sampling the soils, the nature of the site and any related soil profile descriptions or soil chemical data.

comments2: additional, or a continuation of, comments1

Space for additional free text of up to a further 255 characters.

keywords: keywords to describe the data and methodologies

This field allows the selection of data from the database according to the methodologies used to derive the data. This inevitably means that some standardisation of terminology to describe the various techniques had to be made and so it may not agree entirely with that recorded in either of the comment fields.

number_hor: number of horizons sampled per profile

This field provides the number of related samples in a profile, however, this information was not always given, particularly where a horizon was sampled in replicate. As the combination of geo-reference and soil horizon notation provides a unique identifier, it is a simple matter to derive this information as and when needed and so it may be of limited value. Where this information was missing, -9 was entered.

rating: subjective rating of the quality of the data, made by the data owner of contributor

In order to keep some compatibility with the UNSODA database, contributors were allowed to give a subjective rating to the quality of their data using the numbers 1-10. Where they did not wish to do this, -9 was entered.

rated_by: name of the person rating the data

Name of the person rating the data, this will normally be the owner of the data. If the data were not given a rating, then NA was entered.

2.4.2 SOIL_PROPS Table

This table of soil properties mainly holds pedological data and the soil data necessary for deriving pedotransfer functions. In general the data held are primary data although this table also holds the Mualem-van Genuchten parameters contributed by network partners where the methodologies used gave these as output rather than paired $K(h)$ or $\theta(h)$ data. Similarly, where a system of particle size distribution other than the FAO/USDA was used, these data had to be standardised and the proportions of the various size fractions according to the FAO system estimated (see Chapter 3). These estimates are stored in this table along with those particle size distributions determined using the FAO/USDA system. A field called *flag_50* indicates whether the data are estimated (estim) or directly measured (actual).

The attribute, which links this table with the previous one, is the *gridref*. The *horizon* designation is used to link it to subsequent tables, which hold the soil hydraulic data. Again, the fields in this table are largely compatible with UNSODA and there are comments on the methods used to collect the data in free text format.

gridref: geo-reference to 1 m resolution using a European standard system

This will be the same as the geo-reference given in the BASICDATA table and functions as the unique identifier for all tables. Based on a European standard, this system will give a resolution to within 1 m.

horizon: horizon designation following FAO guidelines

The horizon designation is the secondary key which, when used in conjunction with *gridref*, uniquely identifies each sample. It follows the FAO system published in *Guidelines for soil description, 1990, 3rd Ed.* and carries the main pedological information which was used to stratify the data prior to the derivation of the pedotransfer functions. The horizon notation is spaced according to a set of rules to allow quick and accurate selection from the database (Fig. 3). The first space is normally reserved for a numeral which identifies lithological discontinuities within the profile however, in cases where a horizon has been buried, for example, by alluvial or colluvial deposits, a 'b' is placed in this character space. Under the FAO system of horizon notation, this suffix is normally placed at the end of the sequence, however, as there is likely to be a major change in the soil hydraulic properties of a horizon after burial, the 'b' subhorizon designation is placed in the first character space to make it more prominent.

The next two character spaces accommodate the Master horizon designation, while the fourth and fifth spaces are for other subhorizon designations. The sixth space is for the numeric designation of vertical subdivisions. Where the sampling of a soil horizon at one location (that is, within one profile) has been replicated, the horizon notation contains a suffix in the last character space in the field for example _A _p__a and _A _p__b and so on (where _ represents a space). Normally, these suffices are in alphabetic order beginning with 'a' but in one data set 'm' and 'n' were used to clarify the distinction between replicates taken for different methods of determining soil hydraulic conductivity.

	A		p			a
	A		p			b
2	B	C	g	x	1	a
b	A		h			

Fig. 3 Horizon designation rules according to FAO (1990)

top_depth: upper sample depth

The upper sample depth or the upper depth of the horizon (cm), whichever was given.

bot_depth: lower sample depth

The lower sample depth or the lower depth of the horizon (cm), whichever was given.

structure1: primary soil structure (following FAO Guidelines)

A brief description of the primary soil structure of the soil horizon mainly according to the FAO definitions and ped size classes (FAO, 1990) for example, 'moderate medium subangular blocky'. However, where other systems of describing the soil structure were used and which could not be converted to the FAO system, this information has been retained within HYPRES as it was felt that some description of the soil structure was preferable to none. In some cases no primary soil structure was recorded and this is denoted by ND.

structure2: secondary soil structure (following FAO Guidelines)

This field describes any secondary structure in the horizon in the same manner as above. If the secondary soil structure has not been recorded, or is not present, then the notation ND is used.

clay: percentage of clay (< 2 μm)

The percentage of the < 2000 μm fraction that is in the FAO size range of clay particles, that is, < 2 μm. Where this size fraction was not directly determined, the proportion of each size fraction were stored in the table RAWPSD and the proportion of the particles in the clay size range were determined by an estimation procedure which is described in Chapter 3. A value of -9 indicates that the clay content was not determined, these are often organic horizons.

silt: percentage of silt (2-50 μm)

The percentage of the < 2000 μm fraction that is in the FAO size range of silt particles, that is, 2-50 μm. Where this size fraction was not directly determined, the proportion of each size fraction were stored in the table RAWPSD and the proportion of the particles in the silt size range were determined by an estimation procedure which is described in Chapter 3. A value of -9 indicates that the silt content was not determined, these are often organic horizons.

sand: percentage of sand (50-2000 μm)

The percentage of the < 2000 μm fraction that is in the FAO size range of sand particles, that is, 50-2000 μm. Where this size fraction was not directly determined, the proportion of each size fraction were stored in the table RAWPSD and the proportion of the particles in the sand size range were determined by an estimation procedure which is described in Chapter 3. A value of -9 indicates that the sand content was not determined, these are often organic horizons.

ksat: measured saturated hydraulic conductivity (cm day^{-1})

The measured saturated hydraulic conductivity of the horizon in cm day^{-1}. The method to determine this property is given in the *comment* field and a brief description given in *keywords* field. A value of -9 indicates that this attribute has not been determined. This attribute is different from the *mvg_ks*, which is derived from a curve fitting procedure during the parameterisation of the *K(h)* relationship.

satwat: measured saturated water content (as a proportion of soil volume)

The measured saturated water content expressed either as a proportion of the total sample volume or as a proportion of the fine earth fraction (that is, < 2000 μm) which is indicated in the *comments* field. The method of determination is given briefly in the *comments* and *keywords* fields if appropriate and if different from the method used to determine the soil moisture retention curve. The value -9 is entered where this attribute was not determined. This attribute is different from the *mvg_sat* which is derived from a curve fitting procedure during the parameterisation of the $\theta(h)$ relationship.

bulk_den: dry bulk density (g cm^{-3})

The soil dry bulk density expressed in g cm^{-3}. A value of -9 is entered where this attribute has not been determined.

particle_den: particle density (g cm^{-3})

The measured density of the soil particles in g cm^{-3}. A value of -9 is entered where this attribute has not been determined.

porosity: total soil porosity

The measured total porosity. This attribute has been retained within HYPRES to remain compatible with UNSODA, and is often given as being equal to the saturated water content. This value can be expressed as a proportion of the total soil volume or as a proportion of the < 2000 μm fraction and this is indicated in the *comments* field. A value of -9 is entered where this attribute was not determined.

org_mat: organic matter content

The percentage organic matter content rather than the organic Carbon content was recorded in order to keep compatibility with UNSODA. In general, the organic matter contents were derived by multiplying the organic Carbon values by 1.724 (Nelson and Sommers, 1982) This value is expressed as a percentage of the < 2000 μm soil fraction. A value of -9 is entered where this attribute has not been determined.

mvg_sat: contributed Mualem-van Genuchten (mvg) parameter of saturated water content

The Mualem-van Genuchten (mvg) parameter of saturated water content as determined using inverse, one-step and multi-step outflow methods only. The methodology was recorded in the *comment* field. This Mualem-van Genuchten parameter is a curve fitting parameter and is generally not equal to either total porosity or to the saturated water content and so it merely defines the starting point of the fitted curve (van Genuchten et al., 1991). This parameterisation procedure was also applied consistently over the remainder of the dataset and the parameters stored in the HYDRAULIC_PROPS table.

mvg_resid: contributed Mualem-van Genuchten (mvg) parameter of residual water content

The Mualem-van Genuchten parameter of residual water content as determined using inverse, one-step or multi-step outflow methods. The methodology being recorded in the *comments* field. The Mualem-van Genuchten parameter of residual water content defines the end point of the fitted curve but is also merely a curve fitting parameter and may not represent the true residual water content of the soil (van Genuchten et al., 1991).

mvg_alpha: contributed Mualem-van Genuchten (mvg) parameter, alpha

The Mualem-van Genuchten parameter, α, which is an empirical constant that defines the shape of the curve. The values stored in this table are all derived from inverse, one-step or multi-step outflow methods.

mvg_n: contributed Mualem-van Genuchten (mvg) parameter, n

The Mualem-van Genuchten parameter, n, which is an empirical constant that defines the shape of the curve. The values stored in this table are all derived from inverse, one-step or multi-step outflow methods.

mvg_m: contributed Mualem-van Genuchten (mvg) parameter, m

The Mualem-van Genuchten parameter, m, which is an empirical constant that defines the shape of the curve. The values stored in this table are all derived from inverse, one-step or multi-step outflow methods.

mvg_l: contributed Mualem-van Genuchten (mvg) parameter, l

The Mualem-van Genuchten parameter l is a pore-connectivity parameter of relevance only to the description of the hydraulic conductivity/pressure head relationship. The values stored in this table are all derived from inverse, one-step or multi-step outflow methods.

mvg_ks: contributed Mualem-van Genuchten (mvg) parameter of saturated hydraulic conductivity

The Mualem-van Genuchten parameter K_s is notionally the hydraulic conductivity at saturation. Due to the likelihood of large increases in conductivity with small changes in pressure head near to saturation, this parameter is best seen as a fitting parameter and not necessarily equal to the measured saturated hydraulic conductivity *(ksat)*. The values stored in this table are all derived from inverse, one-step or multi-step outflow methods.

flag_50: indicates whether the 50 μm particle size fraction was measured or estimated

A flag indicating for which horizons an interpolation of the particle size distribution was made. Although this procedure was applied mainly to the prediction of the proportion of particles in the 2-50 μm range, there was also a need to predict for the < 2 μm particle size fraction in some instances (Chapter 3). Where data are estimated, estim was recorded and where directly measured, actual, is recorded. Where this was not applicable, for example in organic horizons, NA was used.

comments: comments on methodologies used to derive the above values

Comments on any aspects of the measurement of the attributes in this table, for example, saturated water content or conductivity, methods for determining particle size or organic matter contents and, in particular, an indication of which soil volume the porosity values are related to, the derivation of the Mualem-van Genuchten parameters and whether the soil sample was undisturbed or not.

keywords: keywords to describe measurement techniques

The keywords which describe the methods used. These are standardised throughout in order to facilitate data manipulation.

2.4.3 HYDRAULIC_PROPS Table

As the soil hydraulic data stored in HYPRES were derived by many different methods, they had to be standardised in some way prior to the development of the pedotransfer functions. This was done by fitting the Mualem-van Genuchten equations (van Genuchten et al., 1991) to each unique sets of $\theta(h)$ and/or $K(h)$ data where there were sufficient data and where these data accorded with the shape of the hypothesised curves (see Chapter 3). The resulting parameters were stored in the HYDRAULIC_PROPS table (Appendix 2) and are designated *dmvg_...* in order to make a clear distinction between these derived parameters and those in the SOIL_PROPS table. These parameters were also subsequently used to calculate moisture retention and hydraulic conductivities at 14 different pressure heads for each soil horizon including the replicates. These derived hydraulic data are also stored in this table and are probably the data that will be the most appropriate for regional scale land evaluations, derivation of class pedotransfer functions and perhaps in regional scale simulation modelling.

gridref: geo-reference to 1 m resolution using a European standard system

This will be the same as the geo-reference given in the BASICDATA table and functions as the primary key for all tables. This allows the derived hydraulic data to be linked with the methodological and environmental information. Based on a European standard, this system will give a resolution to within 1 m.

horizon: horizon designation following FAO guidelines

The secondary key, which, in conjunction with the geo-reference, forms the unique identifier, therefore it is vital that the soil horizon notation exactly matches that given in the SOIL_PROPS table (and all the remaining tables) so that data from the two tables can be matched, thus linking pedological information with soil hydraulic properties.

dmvg_sat: derived Mualem-van Genuchten parameter of saturated water content

The Mualem-van Genuchten parameter of saturated water content as derived during the procedure to standardise the hydraulic data in HYPRES (Chapter 3). This Mualem-van Genuchten parameter is a curve fitting parameter and is generally not equal to either total porosity or to the saturated water, particularly in those soils which have a bimodal pore size distribution, therefore, it can be viewed as merely defining the starting point of the fitted curve (van Genuchten et al., 1991).

dmvg_res: derived Mualem-van Genuchten parameter of residual water content

This Mualem-van Genuchten parameter of residual water content defines the end point of the fitted curve, and as previously explained, is generally held to be merely a curve fitting parameter and not to represent the true residual water content of the soil (van Genuchten et al., 1991). The parameter was derived during the procedure to standardise all the soil hydraulic data in HYPRES (where this was possible) and is described in Chapter 3.

dmvg_alpha: derived Mualem-van Genuchten parameter alpha

The Mualem-van Genuchten parameter, α, which is an empirical constant that defines the shape of the curve and was derived during the procedure used to standardise the soil hydraulic data.

dmvg_n: derived Mualem-van Genuchten parameter n

The Mualem-van Genuchten parameter, n, which is an empirical constant that defines the shape of the curve and was derived during the procedure used to standardise the soil hydraulic data.

dmvg_m: derived Mualem-van Genuchten parameter m

The Mualem-van Genuchten parameter, m, which is an empirical constant that defines the shape of the curve and was derived during the procedure used to standardise the soil hydraulic data.

dmvg_l: derived Mualem-van Genuchten parameter l

The Mualem-van Genuchten parameter l is a pore-connectivity parameter of relevance only to the description of the $K(h)$ relationship (hydraulic conductivity *vs* pressure head) and was derived during the procedure used to standardise the soil hydraulic data.

dmvg_ks: derived Mualem-van Genuchten parameter of saturated hydraulic conductivity

The Mualem-van Genuchten parameter K_s is the hydraulic conductivity at saturation. Due to the possibility of large increases in conductivity with small changes in pressure head near to saturation, this parameter is best seen as a fitting parameter and not necessarily equal to the measured saturated hydraulic conductivity (*ksat*). Again this parameter was derived during the procedure used to standardise the soil hydraulic data.

***theta0:** derived saturated water content*

After the soil moisture retention and hydraulic conductivity curves were parameterised using the Mualem-van Genuchten equations, new $\theta(h)$ and $K(h)$ relationships were determined from the parameters for 14 different pressure heads between 0 and -16 000 cm (Chapter 3). These data are also stored in the HYDRAULIC_PROPS table along with the parameters and identified by *gridref* and *horizon*. The *theta0* value is essentially the Mualem-van Genuchten parameter *mvg_sat* (the predicted saturated water content) but has been rounded to only three decimal places. This is rarely the same as the saturated water content recorded in the SOIL_PROPS Table.

***theta10:** derived water content at -10 cm pressure head*

The moisture content at -10 cm pressure head expressed as a proportion of the soil volume and predicted from the Mualem-van Genuchten parameters.

***theta20 to theta16000:** derived water content at -20 cm to -16 000 pressure head*

The moisture content at -20, -50, -100, -200, -250, -500, -1000, -2000, -5000, -10 000, -15 000, and -16 000 cm pressure head expressed as a proportion of the soil volume and predicted from the Mualem-van Genuchten parameters.

***cond0:** derived saturated hydraulic conductivity*

The saturated hydraulic conductivity as predicted from the Mualem-van Genuchten parameters. This value will rarely be the same as the *ksat* value given in the SOIL_PROPS table due to the inability of the Mualem-van Genuchten parameterisation to take full account of the hydraulic properties of soils with bimodal pore systems.

***cond10:** derived hydraulic conductivity at -10 cm pressure head*

The hydraulic conductivity at -10 cm pressure head as predicted from the Mualem-van Genuchten parameters.

***cond20 to cond 16000:** derived hydraulic conductivity at -20 cm to -16 000 pressure head*

The hydraulic conductivity at -20, -50, -100, -200, -250, -500, -1000, -2000, -5000, -10 000, -15 000, and -16 000 cm pressure head as predicted from the Mualem-van Genuchten parameters.

2.4.4 RAWPSD Table

The RAWPSD table holds the particle size data on those soil samples where a system other than the FAO classification of particle size class was used or where there were many more classes than the three stored within the SOIL_PROPS table. Although the RAWPSD table has only two fields in addition to *gridref* and *horizon*, which are, *psize* and *pcent*, the table holds as many multiple pairings as were given. The data were subsequently used in an interpolation procedure (Chapter 3) to provide approximations to the FAO classes where necessary and which were then stored in the appropriate fields in the SOIL_PROPS table. In most instances there will be no need to access this table.

gridref: geo-reference to 1 m resolution using a European standard system

As previously described. The geo-reference and horizon designations are exactly as those given in the SOIL_PROPS table in order to maintain referential integrity within the database.

horizon: horizon designation following FAO guidelines

As this field is, in conjunction with the geo-reference, the unique identifier, the soil horizon notation exactly matches that given in the SOIL_PROPS table (and all others). This is of particular importance where the particle size classes had to be standardised to the FAO system and the interpolated data stored in the SOIL_PROPS table.

psize: upper particle size range (μm)

The particle size class. In order to allow this field to be entirely numeric, which simplifies data manipulation, and to reduce the volume of data stored, the first particle size indicated should be read as 'less than'. The second, should then be taken to be the range between the first and second and so on, for example, in the table where the particle size ranges followed the British Standard Texture Classes we have:

psize	pcent
2	12
60	40
2000	48

This means that there is 12 percent clay (< 2 μm), 40 percent 'silt' (2-60 μm) and 48 percent 'sand' (60-2000 μm).

pcent: percentage of particles within the specified range

The proportion of particles in the size range specified expressed as a percentage of the total mass of the soil fraction, which is less than 2000 μm in size.

2.4.5 RAWRET Table

The RAWRET table (Appendix 2) holds all the contributed data on the $\theta(h)$ relationship, that is, water content against pressure head. The geo-reference and horizon designations are consistent with previous tables in order to keep all the data from one determination intact. This table holds as many $\theta(h)$ determinations as were made for each sample. A description of the methods used will be found in the table BASICDATA.

gridref: geo-reference to 1 m resolution using a European standard system

As previously described. The geo-reference and horizon designations should matches those in all other tables in order to maintain referential integrity within the database.

horizon: horizon designation following FAO guidelines

As this field is, in conjunction with the geo-reference, the unique identifier, the soil horizon notation exactly matches that given in the SOIL_PROPS table (and all others) thus data from any table can be matched, linking pedological information with both derived and measured soil hydraulic properties.

flag: Indicates whether laboratory (l) or field (f) measurement.

Indicates whether the moisture retention data were derived from measurements made in the laboratory (l) or in the field (f).

head: value of the pressure head

The absolute value of the pressure head in cm of water at which the moisture content was determined. Therefore this is expressed as a positive number, although this attribute is in fact, negative.

theta: moisture retained at the specified pressure head

The soil moisture content at a stated pressure head expressed as a proportion of the volume of soil. An indication as to whether the soil volume is the total volume which includes stones (for example, from field measurements) or the volume of the fine earth fraction only, that is, the volume of the soil minus the volume of stones, is given in the comments fields of the BASICDATA Table. This latter volumetric measurement does not necessarily imply that the samples were disturbed.

2.4.6 RAWK Table

The RAWK table holds all the contributed data on the hydraulic conductivity and will be able to hold as many pairs of conductivity *vs* pressure head $K(h)$ determinations as were made for each sample. In a few instances conductivity is expressed as a function of water content. These are indicated in the *ind_var* field.

gridref: geo-reference to 1 m resolution using a European standard system

As previously described. The geo-reference and horizon designations should exactly match those in the previous tables in order to maintain referential integrity.

***horizon**: horizon designation following FAO guidelines*

As this field is, in conjunction with the geo-reference, the unique identifier, the soil horizon notation exactly matches that given in the SOIL_PROPS table (and all the remaining tables) thus data from the tables can be matched, linking pedological information with soil hydraulic properties.

flag: Indicates whether laboratory (l) or field (f) measurement.

An indication as to whether the conductivity data were derived from measurements made in the laboratory (l) or in the field (f).

***ind_var**: indicates whether the conductivity is related to pressure head or moisture content*

An indication (*ind*icator *var*iable) as to whether the hydraulic conductivity is related to pressure head (head) in cm of water, expressed as a positive number or moisture content (theta).

***var**: value of the indicator variable*

The value of the related *var*iable in cm of water whether against pressure head or the moisture content and expressed as a proportion of the soil volume.

***cond**: hydraulic conductivity at the specified value cm day^{-1}*

The measured hydraulic conductivity at the pressure head or moisture content indicated in the *var* field expressed in cm day^{-1}.

3 Pre-processing of data

3.1 Standardisation of particle-size data

3.1.1 Introduction

Data in the HYPRES database were collected from institutions in 10 EU countries and from Slovakia. In these various countries, different soil classification systems are used with the consequence that there are inconsistencies in the class intervals used to describing the soil particle-size distribution. As a result, soil texture information received from the different institutions was not always compatible and needed to be standardised before it could be used in the project.

The 1 : 1 000 000 scale Soil Geographical Database of Europe (Jamagne et al., 1994) uses the same particle-size class intervals as FAO (1990) and the USDA (1951), where clay is defined as the particle-size fraction < 2 µm, silt as the fraction between 2 and 50 µm and sand as the fraction between 50 and 2000 µm. To achieve compatibility between HYPRES and the Soil Geographical Database of Europe, it was decided to standardise the particle size data to these size limits. Table 3 gives an overview of the particle size limits commonly used in the different countries.

Table 3 Particle-size limits commonly used in the different European countries.

Country	particle-size limits (µm)
Belgium	2-10-20-50-100-200 (or 250)-500-1000-2000
Denmark	2-20-63-125-200-500-2000
England	2-20-60-100-200-600-2000
France	2-50-2000
Germany	2-(6.3)-20-63-(125)-200-630-2000
Greece	2-6-20-60-200-600-2000
The Netherlands	2-16-50-105-150-210-300-2000
Italy	2-50-2000
Northern Ireland	2-60-2000
Portugal	2-20-200-2000
Scotland	2-60-2000
Slovak Republic	1-10-50-250-2000
Spain	2-20-2000
Sweden	2-6-20-60-200-600-2000

There were close to 30 different particle size limits received. Countries like Belgium, France, Italy and the Netherlands use particle-size classes in their national soil classification system which are compatible with the FAO/USDA system. For other countries standardisation of particle-size classes was required to achieve compatibility. During work on a similar type of database which was also derived from a multitude of sources, Batjes (1996) reported that data from those soils with non-standard particle-size limits had to be excluded from the analysis. In the case of the HYPRES database, this would have resulted in a considerable loss of data. Therefore, a study was initiated to find methods applicable to the prediction of missing points on the cumulative particle-size distribution curves of the individual soil horizons and so to interpolate the size fractions according to the FAO/USDA system.

Several studies suggest that the particle-size distribution of soils shows an approximately log-normal distribution (Campbell, 1985; Shirazi and Boersma 1984). However, soils with bimodal particle-size distributions are also likely to occur (Walker and Chittleborough, 1986). Buchan (1989) investigated the applicability of lognormal models for describing soil particle-size distributions and found that these were only applicable for about half of the soil texture classes. Buchan (1989) also investigated how the number of particle-size classes determined affected the shape of the cumulative particle-size distribution. More complex cumulative distributions require a greater number of parameters for a full description. To date, the loglinear interpolation procedure (for example, Tietje and Hennings, 1996) has mainly been used to estimate the proportions of particles in each size fraction of the FAO/USDA class limits where no direct measurement exists. However, other methods are possible and Nemes et al. (submitted) presents some alternatives to the loglinear interpolation procedure. The accuracy of the various procedures was evaluated using data from the HYPRES database and from the Soil Information System of the Netherlands (Finke, 1995). A summary of the work of Nemes et al. (submitted) is presented in this report.

3.1.2 Materials and methods

3.1.2.1 Testing and reference datasets

Particle-size data were extracted from both the HYPRES database and the Soil Information System of the Netherlands in order to develop and test methods for the interpolation of missing particle size data. The selected data were stratified into three groups: a reference dataset and two testing datasets.

1. *Reference dataset* was created by randomly extracting data from the Soil Information System of the Netherlands and is considered to be representative for the entire Dutch database. The reference dataset contains 9607 individual soil horizons and was used to develop one of the interpolation procedures evaluated in this study. The particle-size distribution of the soils in the reference dataset encompasses a wide range of soil texture classes (Fig. 4).

2. The Testing Dataset 1 comprises the remaining data from the Dutch Soil Information System and contains data from 3453 individual soil horizons.

3. The Testing Dataset 2 was extracted from the HYPRES database and contains 1524 soil horizons all originating from Germany. These data were chosen as the particle-size fractions had been derived for numerous particle-size classes giving well quantified cumulative distribution curves.

Soils in dataset 2 had considerably finer textures with higher average clay and silt contents as compared to the soils in dataset 1.

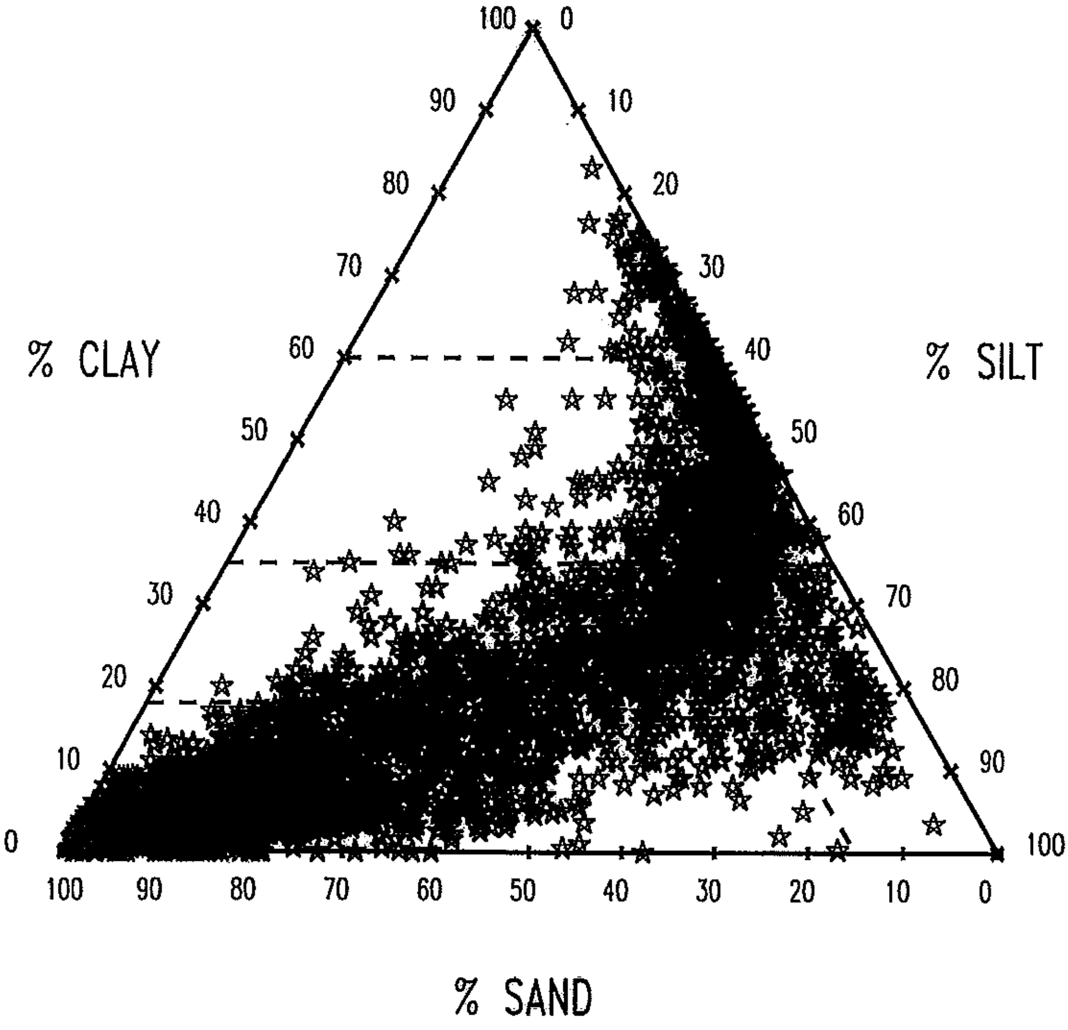


Fig. 4 Texture triangle with data points of the reference dataset

3.1.2.2 Estimation procedures

Four interpolation procedures were evaluated using the two testing datasets each of which requires that the particle-size class distribution be transformed to a logarithmic scale. The variables *lndistance* and *alpha* defined in Figure 5 were both used in testing and evaluating the efficiency of the interpolation techniques. In this case *lndistance* represents the distance on a natural logarithmic scale between two particle-size limits neighbouring the limit for which the fraction has to be estimated. *Alpha* shows the average difference between the cumulative percentages of the above mentioned two neighbouring particle-size limits.

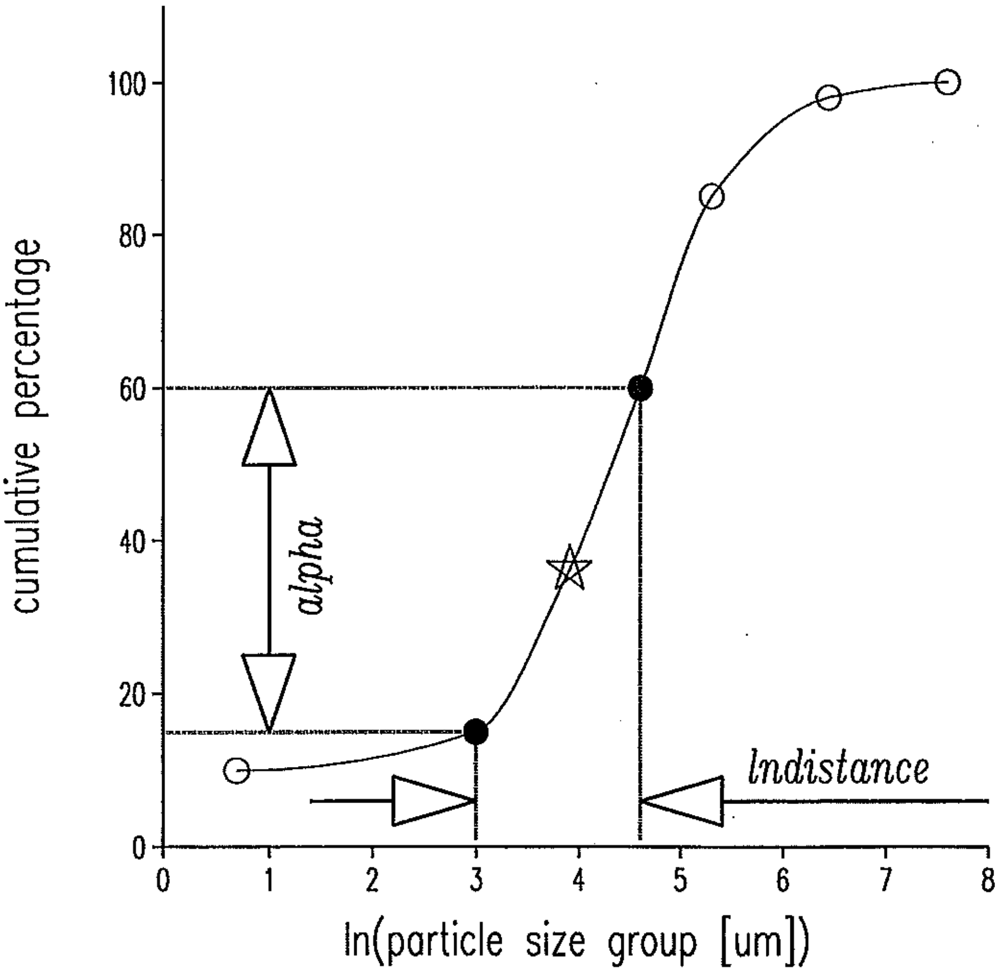


Fig. 5 Definition of the variables lndistance *and* alpha *of the cumulative particle-size distribution*

Loglinear interpolation

In the past, loglinear interpolation of the cumulative particle-size distribution curve was often used. In this procedure, the estimation of the fraction for a particular particle-size limit where no measurement had been made, was based on the assumption of a loglinear relation between two neighbouring points with known particle size classes and measured proportions. Mathematical notation of the loglinear interpolation is:

$$CP_n = CP_{n-1} + \frac{\ln(PSL_n) - \ln(PSL_{n-1})}{\ln(PSL_{n+1}) - \ln(PSL_{n-1})}\,(CP_{n+1} - CP_{n-1})$$

where *CP* is the cumulative percentage value on the particle-size distribution curve, *PSL* represents the particle-size limits in question and notations *n*, *n-1*, *n+1* stand for the missing particle-size limit, the limit before and the limit after the missing limit respectively.

Gompertz procedure
The Gompertz curve can also be fitted to the measured cumulative particle-size distribution and is similar to the well known logistic curve, however, it allows non-symmetry whereas the logistic curve does not. The mathematical notation for this curve is:

$$y_i = \alpha + \gamma \exp(-\exp(-\beta(x_i - \mu)))$$

where α, β, γ and μ are the shape parameters describing a specific curve. If $\beta > 0$ then the curve is called *right sided.* This results in a steeper rise of the monotonous curve close to the lower asymptote. Contrarily, if $\beta < 0$ it means a steeper rise close to the upper asymptote, and is called *left sided.* Testing showed that, in most cases, the *left sided* curve gave a better fit to the measured points. As a consequence, investigations were restricted to the use of the left sided curve while the right sided and symmetric (i.e. logistic) curve were not used.

Spline procedure
The highly flexible spline procedure was also applied. Smoothing splines are complicated functions constructed from segments of cubic polynomials between distinct values of a variable, and constrained to be 'smooth' at the junctions. The parameterisation of the fitted smooth curve is a complicated process in which the degree of smoothness can be controlled. Further details of these models can be found elsewhere (Hastie and Tibshirani, 1990). Various maximum degrees of smoothness of the splines (n) have been tried in this study and n=6 was found to give sufficient accuracy. Further increase of n did not result in any significant increase in accuracy, whereas allowing a smaller maximum degree of smoothness resulted in considerable loss of accuracy.

Similarity procedure using a large reference dataset
A new approach called 'Similarity procedure' is introduced. In this procedure, the reference dataset, which contained several (7 or 8) measured particle-size fractions for all soils, was used. The procedure involves searching for soils in the reference dataset with a particle-size distribution that was the most similar to that of the soil for which data on a particular particle-size limit was missing. Selection of these soils was based on a comparison of the particle-size fractions within those particle-size limits, which were common to both the reference set and the soil under investigation (Fig. 6). Once these soils were selected they were used to calculate the particle-size fraction for the missing particle-size class. This was done through an iteration procedure designed to select the 10 most similar particle size distributions from the reference dataset for which there were data on the unknown size range. The mean proportion of particles in this size range was calculated from the 10 selected distribution curves.

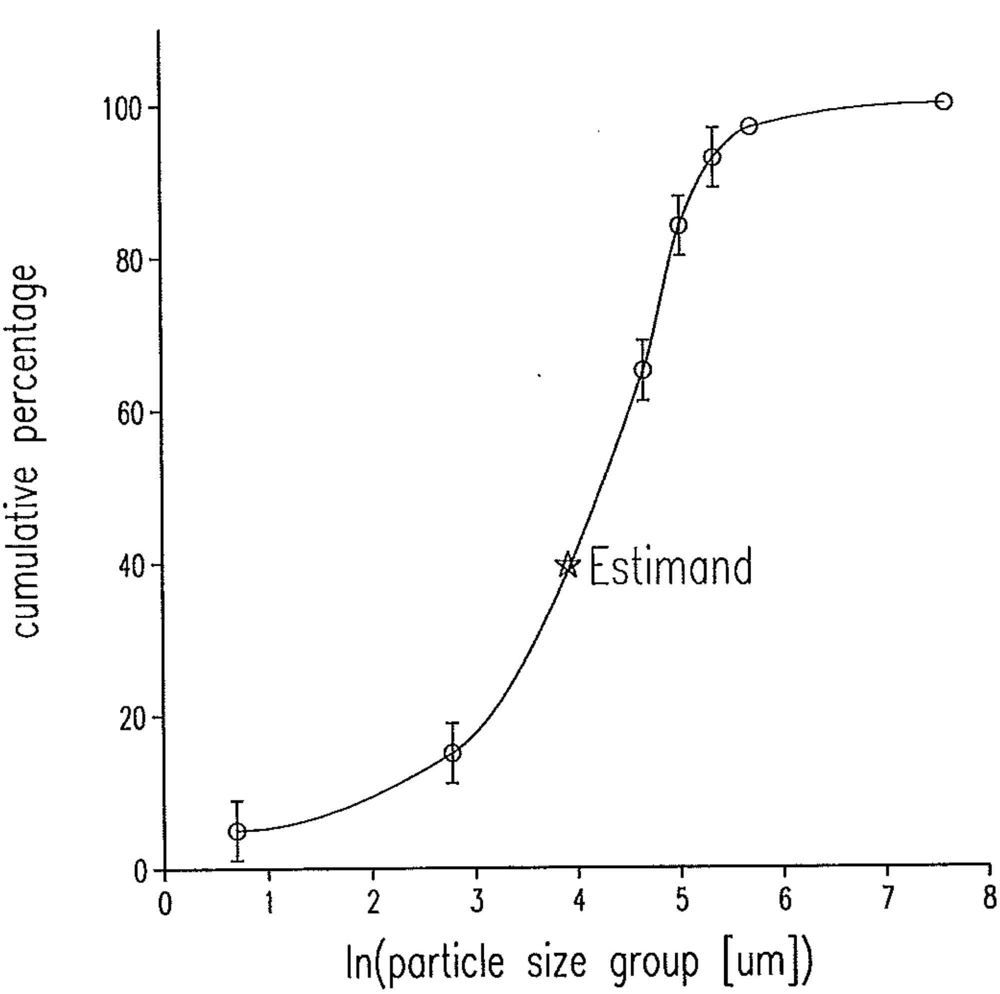


Fig. 6 Visualisation of the 'similarity procedure' for data interpolation

3.1.2.3 Evaluation of the procedures

A number of different tests were conducted on all four interpolation procedures. Selected points on the cumulative particle-size distribution curves were systematically omitted and each interpolation technique was applied to estimate the missing points. Results were compared using the mean squared residual error (MSE) defined as:

$$MSE = (1/n) \sum_{i=1}^{n} (x_i - y_i)^2$$

Where n = number of measured and estimated values, x = measured particle-size fraction, y = estimated particle-size fraction.

3.1.3 Results and discussion

It was found that the accuracy of all methods was highly dependent on the interval between the particle-size limits for which the fractions had been measured and the number of measured data points. All four interpolation methods gave acceptable results for those datasets with the greatest number of measured particle size classes, and especially those where these class intervals were evenly distributed when plotted on a logarithmic scale. However, where data were sparse or unevenly distributed, the various interpolation techniques had different degrees of success in estimating missing data. Table 4 shows the MSE values for the 2 datasets and the 4 procedures. In general the loglinear procedure gives the poorest fit, followed by the spline, the Gompertz procedure and finally the similarity procedure.

Table 4 Results of the sensitivity analysis for the 4 interpolation procedures

	Variable	Procedures			
	ln(distance)	Loglinear MSE	spline MSE	Gompertz MSE	Similarity MSE
Test	2.57	389.30	230.94	92.47	68.45
Dataset 1	2.24	216.00	109.84	76.47	53.42
	1.44	234.00	138.56	55.88	38.38
	1.10	77.96	26.68	21.24	12.22
	0.69	38.52	19.68	16.59	13.58
Test	2.30	273.70	198.40	152.24	123.80
Dataset 2	1.83	132.60	79.14	83.64	87.89
	1.16	32.34	22.50	62.57	7.80

A more detailed analysis of Table 4 shows that, in almost all cases, the loglinear interpolation gave the highest MSE values and therefore the lowest accuracy of the estimation. Fitting a spline curve gave much better results in terms of statistical properties than the loglinear interpolation procedure, however, splines were found to be inaccurate when the neighbouring measured fractions were distant (i.e. *lndistance* was large). The spline procedure became unstable when the number of measured points were less than 4. In general, the Gompertz procedure performed better than the spline procedure and showed much less variation in accuracy with varying *lndistance* than the spline procedure. For *dataset 1,* Gompertz was much better than the splines where particle size limits were widely spaced around the estimation, however, the performance of these two procedures was approximately equal where particle size limits were closely spaced. Applying these methods to *dataset 2*, splines gave considerably better results in the case of closely spaced particle-size limits than the less flexible Gompertz procedure. This may be explained by the bimodal characteristics of many of the soils in *dataset* 2. However, the performance of the Gompertz procedure is surpassed by the 'similarity procedure' which, in general, shows the lowest MSE values. In most cases where *lndistance* is relatively large, the MSE of the loglinear, Gompertz, and spline procedures were an order of magnitude greater than the MSE of the similarity procedure. Where the *lndistance* was short the

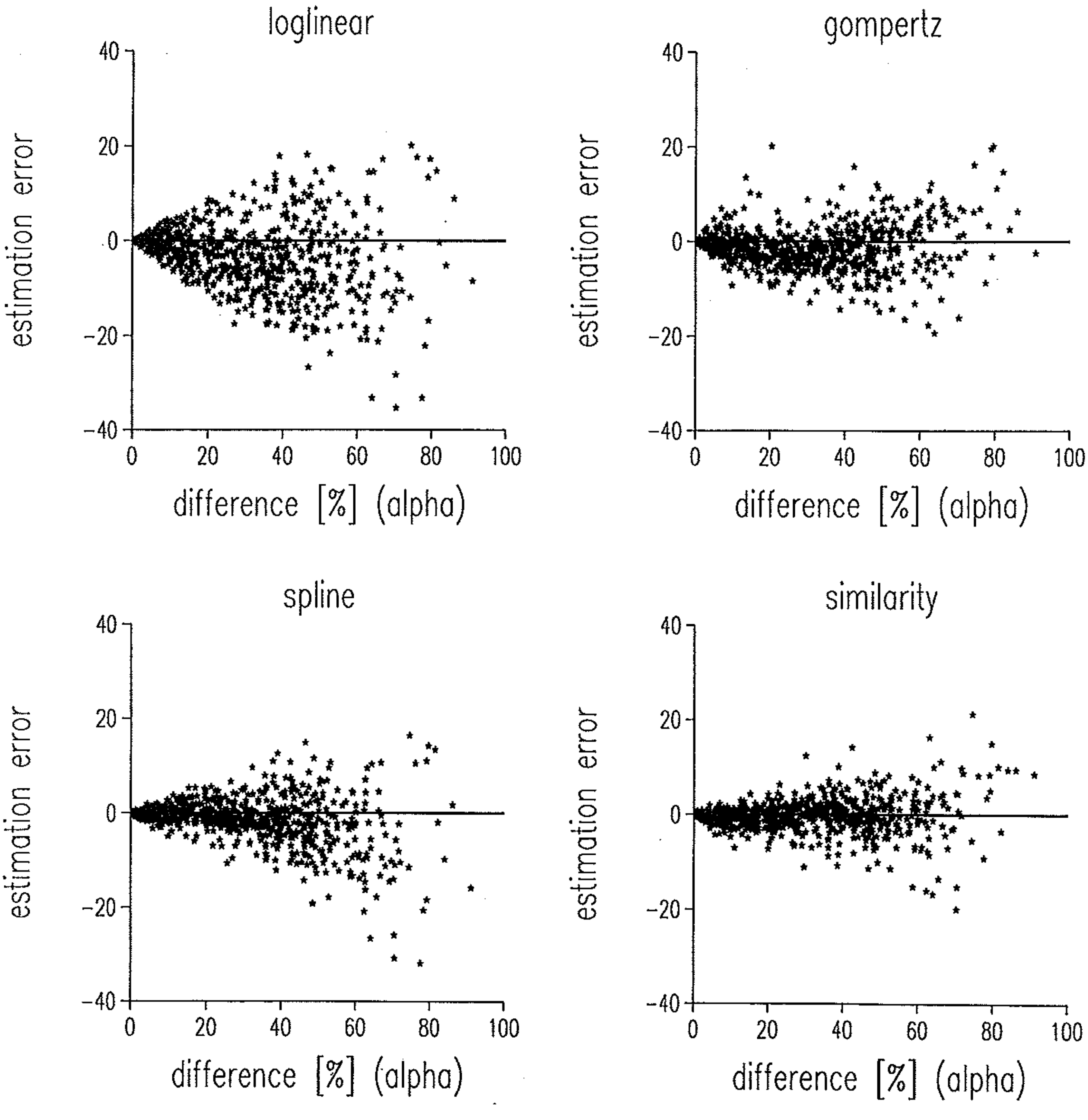


Fig. 7 Visual evaluation of the sensitivity of the four procedures to changes in the alpha *value*

accuracy of the spline and Gompertz procedure (the latter only in case of *dataset 1*) was comparable with that of the similarity method. The loglinear interpolation as well as the spline procedure was greatly affected by the spacing of measured particle-size limits. The Gompertz procedure and the similarity procedure were much less affected.

Figure 7 shows the results of a sensitivity analysis of the four procedures in which the *alpha* values were varied. As shown in Figure 5, *alpha* is the difference between the cumulative percentages at two neighbouring particle-size limits. Estimation errors close to zero in Figure 7 indicate that measured and estimated values did not differ much. The loglinear procedure loses considerable accuracy as *alpha* increases. Whereas the other three procedures show this same phenomenon to a lesser extent. No considerable bias (consistent under or overestimation) was detected for any of the four procedures.

3.1.4 Conclusions and summary of analyses

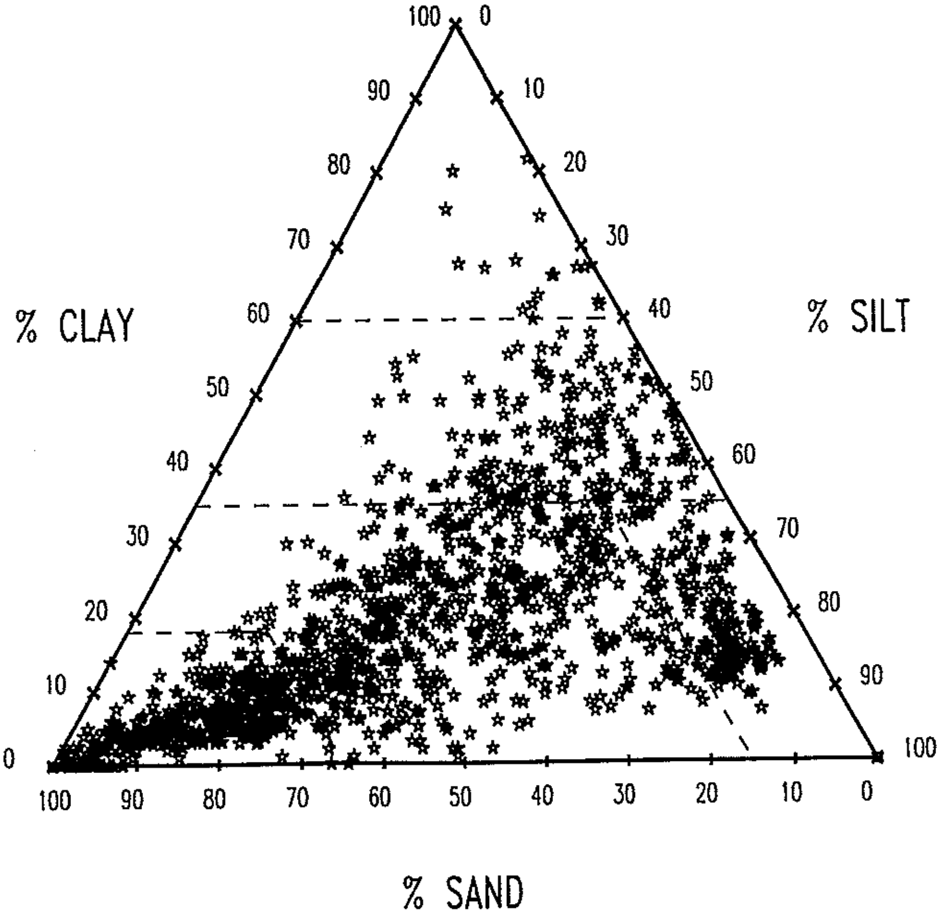
Four different interpolation procedures were evaluated in order to select the best procedure for estimating particle-size fractions where the given particle sizes classes did not accord with the FAO system. The evaluation procedures made use of large and comprehensive datasets of particle-size distributions and it was found that the approach of using a large reference dataset and scanning that set for the most similar soils (the novel similarity procedure in this study) was found to give the best estimations overall. However, where the particle-size distribution differs significantly from those included in the reference dataset, the similarity procedure can not be applied and splines were used instead. Splines have the advantage that they are independent of external reference datasets. Where there were less than 4 measured data points, the Gompertz curve could not be used since it is described by 4 parameters, for example, in the datasets from Scotland or Spain where only 3 points on the particle-size distribution curve were measured. In these cases, the spline procedure was not suitable either. In all cases the loglinear interpolation gave a significantly poorer performance than the other procedures and so the use of this procedure is not recommended. As a criterion of deciding which method to use, a *lndistance* of approximately 1 (Fig. 5 and 6) between two neighbouring particle-size limits was used as threshold. If the distance was less than 1, splines were used where possible and where this value was >1, the similarity method was used. A summary of the procedures finally used for interpolating the different national datasets is presented in Table 5.

Table 5 Procedures used for interpolation of particle-size data of soils from different countries

Country	Sequence of measured particle-size limits (μm)	Applied procedure
Denmark	2-20-63-125-200-500-2000	spline function
Germany	2-(6.3)-20-63-(125)-200-630-2000	spline function
Greece	2-6-20-60-200-600-2000	spline function
Northern Ireland	2-60-2000	similarity procedure
Portugal	2-20-200-2000	similarity procedure
Scotland	2-60-2000	similarity procedure
Spain	2-20-2000	similarity procedure
Sweden	2-6-20-60-200-600-2000	spline function

3.1.5 Application of interpolation techniques

The recommended combination of the similarity procedure and the spline procedure was applied to standardise the particle-size data of the soils in the HYPRES database. The interpolation methods were applied primarily to predict the proportion of soil particles in the silt and sand range, that is from 2-50 μm and from 50 to 2000 μm, although one dataset required predictions in the < 2 μm and the 2-50 μm ranges. More than 50% of the soil horizons in the HYPRES database required interpolation of the particle-size distribution before they could be classified according to the texture classes used by the FAO and the Soil Geographical Data Base of Europe. The results of the interpolations were stored in the HYPRES table, SOIL_PROPS along with a flag indicating that the data are interpolated. In total 4976 soil mineral horizons were classified, 3376 are subsoils and 1600 topsoils. The distribution of soil particle sizes for each topsoil horizon (including the interpolated data) and stratified into topsoils and subsoils is shown in Figure 8a while that for subsoils is shown in Figure 8b.


% CLAY
% SILT
% SAND
100
90
80
70
60
50
40
30
20
10
0

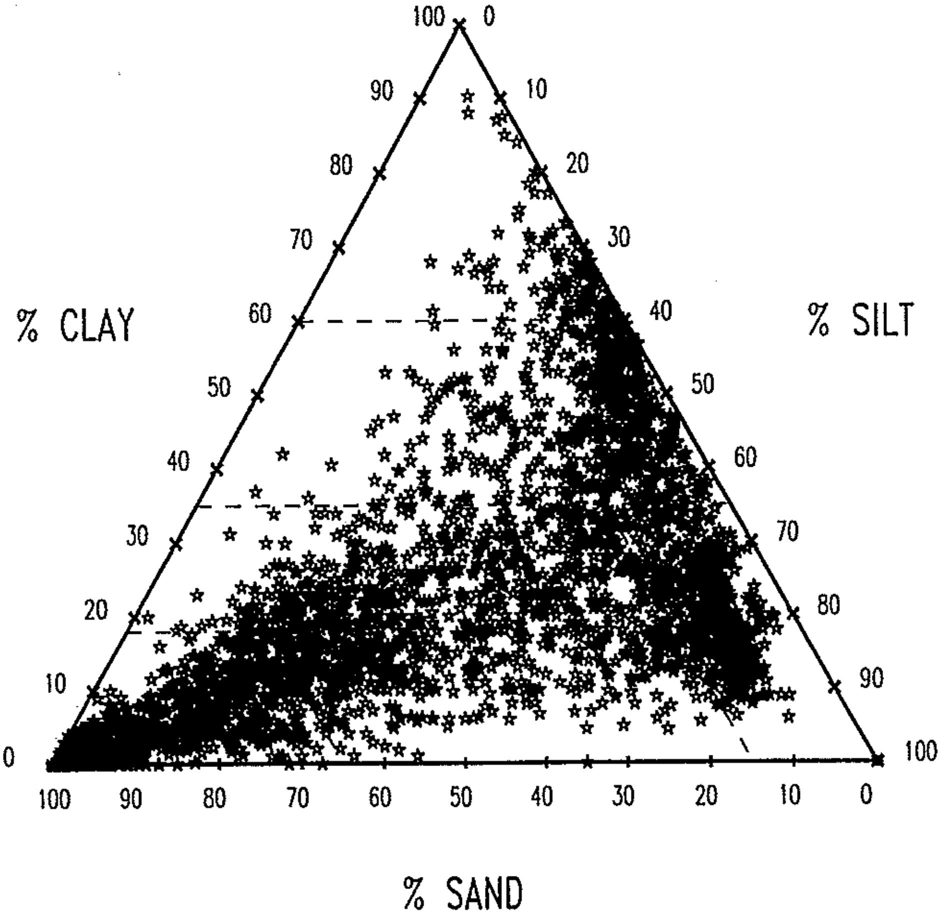


Fig. 8 Textural composition of the 1600 mineral topsoils (a) and 3376 mineral subsoils (b) in the HYPRES database

3.2 Grouping of data into texture classes

Once the particle-size data, which did not conform to the FAO system were standardised they were then grouped into 11 texture/pedological classes, that is, 5 topsoil textures, 5 subsoil textures and 1 organic class. These groups accord with the soil textural data held within the 1: 1 000 000 Soil Geographical Data Base (Jamagne, et al., 1994)

The organic layers were defined as horizons with more than 12 percent organic Carbon when the clay contents were zero and with more than 18 percent organic Carbon where the clay contents were greater than 60 percent (Fig. 9). Those soils with organic Carbon contents between 12 and 18 percent are classified as organic only when the clay content exceeds variable amounts as shown in Figure 9. Where either the texture or organic Carbon data were missing, those horizons, which were deemed by the data contributors to be organic, were designated as such. These have a major horizon designation of 'H' (FAO, 1990).

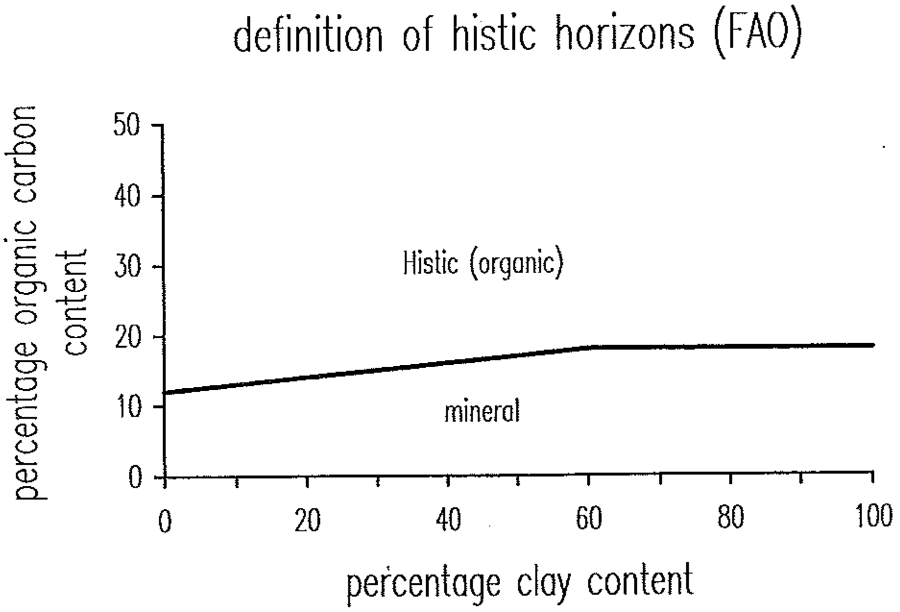


Fig. 9 Definition of histic horizons (FAO)

The remaining, mineral, horizons were stratified according to both texture class (Fig. 10) and pedology. These texture classes are those used in the Soil Geographical Data Base and are defined in Table 6. Those horizons designated as 'A' horizons were placed in the topsoil group while the remainder were placed in the subsoil group. Those horizons, which had pedological characteristics of both topsoils and subsoils such as 'AB' or 'AE' horizons were allocated to a class according to other criteria such as depth, bulk density and organic Carbon contents. The summary of the numbers of horizons in each textural group is presented in Table 7.

Table 6 Criteria for the texture groups of the 1: 1 000 000 Soil Geographical Data Base

C	Coarse	clay < 18% and sand > 65%
M	Medium	18% < clay < 35% and 15% < sand OR clay < 18% and 15% < sand < 65%
MF	Medium-Fine	clay < 35% and sand < 15%
F	Fine	35% < clay < 60%
VF	Very Fine	60% < clay

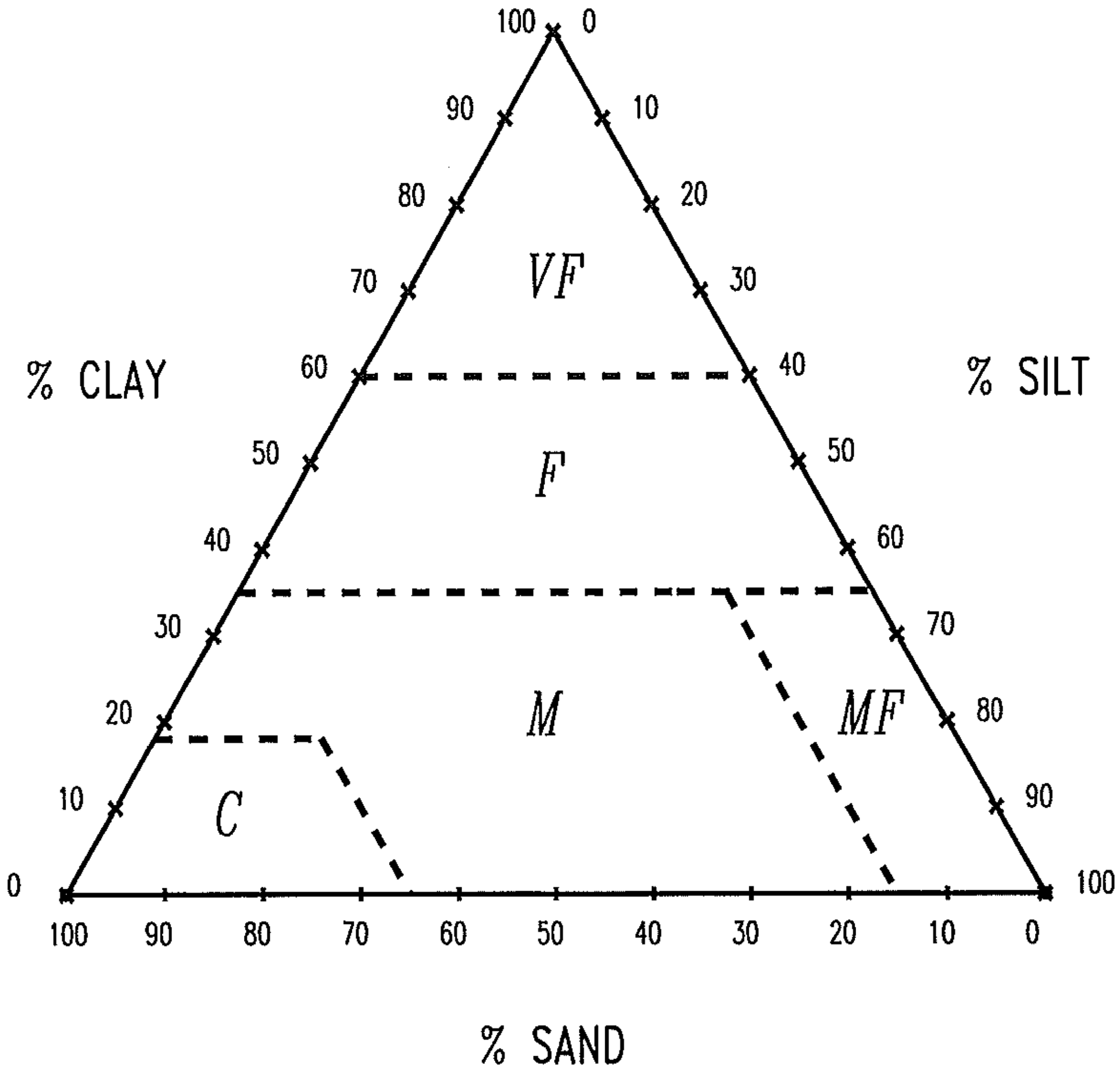


Fig. 10 Definition of soil texture groups according to the EU soil map

Table 7 Number of horizons in each texture class

	Soil texture	Number of horizons
Topsoils	coarse	510
	medium	644
	medium-fine	208
	fine	217
	very fine	21
Subsoils	coarse	947
	medium	1181
	medium-fine	526
	Fine	596
	Very fine	132
	Organic*	148

* Within the organic soils no distinction is made in topsoils and subsoils

3.3 Parameterization of hydraulic data

3.3.1 Introduction

Like the soil textural data, the soil hydraulic data was also derived by various methods. The data for the dry range of the soil moisture retention curve was generally derived through the use of pressure chambers while the majority of the soil moisture retention data in the wet range was derived in two principle ways, by hanging water columns (and related tension tables) and by evaporation. As the evaporation method generally generates many more data points than is usual with the hanging water column, there was a marked imbalance in the number of data pairs for the soil samples in HYPRES. This was also true for the hydraulic conductivity data. Therefore, there was a necessity to also standardise these data prior to the development of pedotransfer function to avoid statistical bias.

3.3.2 Model for parameterization

To facilitate their efficient use in simulation models, measured hydraulic functions may be described with analytical equations. By that procedure, data can also be represented with a set of standard parameters regardless of the method used in their derivation. A wide range of different equations is available for the parameterization of measured hydraulic functions (Vereecken, 1992). In this study volumetric soil water content, θ, and hydraulic conductivity, K, as functions of pressure head, h, are described with the following equations (van Genuchten, 1980):

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1 + \alpha h)^{1-1/n}}$$

$$K(h) = K_s \frac{((1 + \alpha h^n)^{1-1/n} - \alpha h^{n-1})^2}{(1 + \alpha h^n)^{(1-1/n)(l+2)}}$$

In these equations the subscripts r and s refer to residual and saturated values and α, and n and l are parameters that determine the shape of the curve. The residual water content θ_r refers to the water content where the gradient $d\theta / dh$ becomes zero ($h \rightarrow -\infty$). In practice θ_r is the water content at some large negative value of soil-water pressure head. The parameter α (cm^{-1}) approximately equals the inverse of the pressure head at the inflection point where $d\theta / dh$ has its maximum value. The dimensionless parameter n determines the rate at which the S-shaped retention curve turns towards the ordinate for large negative values of h, thus reflecting the steepness of the curve. The dimensionless parameter l determines the slope of the hydraulic conductivity curve in the range of more negative values of h. As follows from the equations, the parameter θ_r affects only the shape of the retention curve while leaving the conductivity function unaffected. The parameter l, on the other hand, affects the hydraulic conductivity only and leaves the retention curve unchanged. The flexibility of the equations in generating different shapes of $\theta(h)$ and $K(h)$ relationships has been demonstrated by a number of researchers (e.g., Hopmans and Overmars, 1986; Wösten and van Genuchten, 1988).

The nonlinear least-squares optimization program RETC (van Genuchten et al., 1991) was used to predict the unknown parameters (θ_r, θ_s, K_s, α, l and n) in both equations simultaneously from measured soil-water retention and hydraulic conductivity data. In the optimization procedure the sums of squares of differences between measured and predicted water contents and between measured and predicted hydraulic conductivities are minimized.

3.3.3 The parameterization procedure

In this study, the unknown parameters such as θ_s, K_s, α, l, and n, were optimised. θ_r was initially set to 0.01 and than later changed if measured data suggested otherwise. Mualem (1976) suggests that l should be, on average, about 0.5. In this study l is not fixed but is considered to be one of the experimental unknowns. In the parameterisation procedure it is assumed that $m = 1 - 1/n$. Use of the RETC program is a semi-automated procedure, which involves visual inspection of the goodness-of-fit of all horizons individually. This is because the least-squares optimisation process may, on occasion, end up in a local but not in the absolute minimum of the error function. After visual inspection, corrections can be made to improve the optimisation

Figure 11a shows an initial fit with RETC using initial values of the model parameters. Figure 11b shows the final fit after the model parameters are optimised in the RETC procedure.

Table 8 summarises the number of measured data available for each texture group. The column *total* refers to the total number of samples classified in each group. The column *processed* refers to the number of horizons that were used in the parameterisation process and that were also used in deriving pedotransfer functions. The differences in the number of horizons occurs as, in some cases, there were insufficient data on the particle sizes while in others there was insufficient measured hydraulic data and therefore could not be parameterised. Those that exhibited values for the model parameters which were substantially different from similar soil horizons were also omitted. This could be due to measurement errors in the particle-size measurement, the interpolation of particle-size data or the measurement of hydraulic. However, these data were not deleted from HYPRES and remain available for future analysis. The column *with K-data* refers to the number of horizons where there were sufficient measured hydraulic conductivity data. This does not include cases when only the saturated hydraulic conductivity value was obtained.

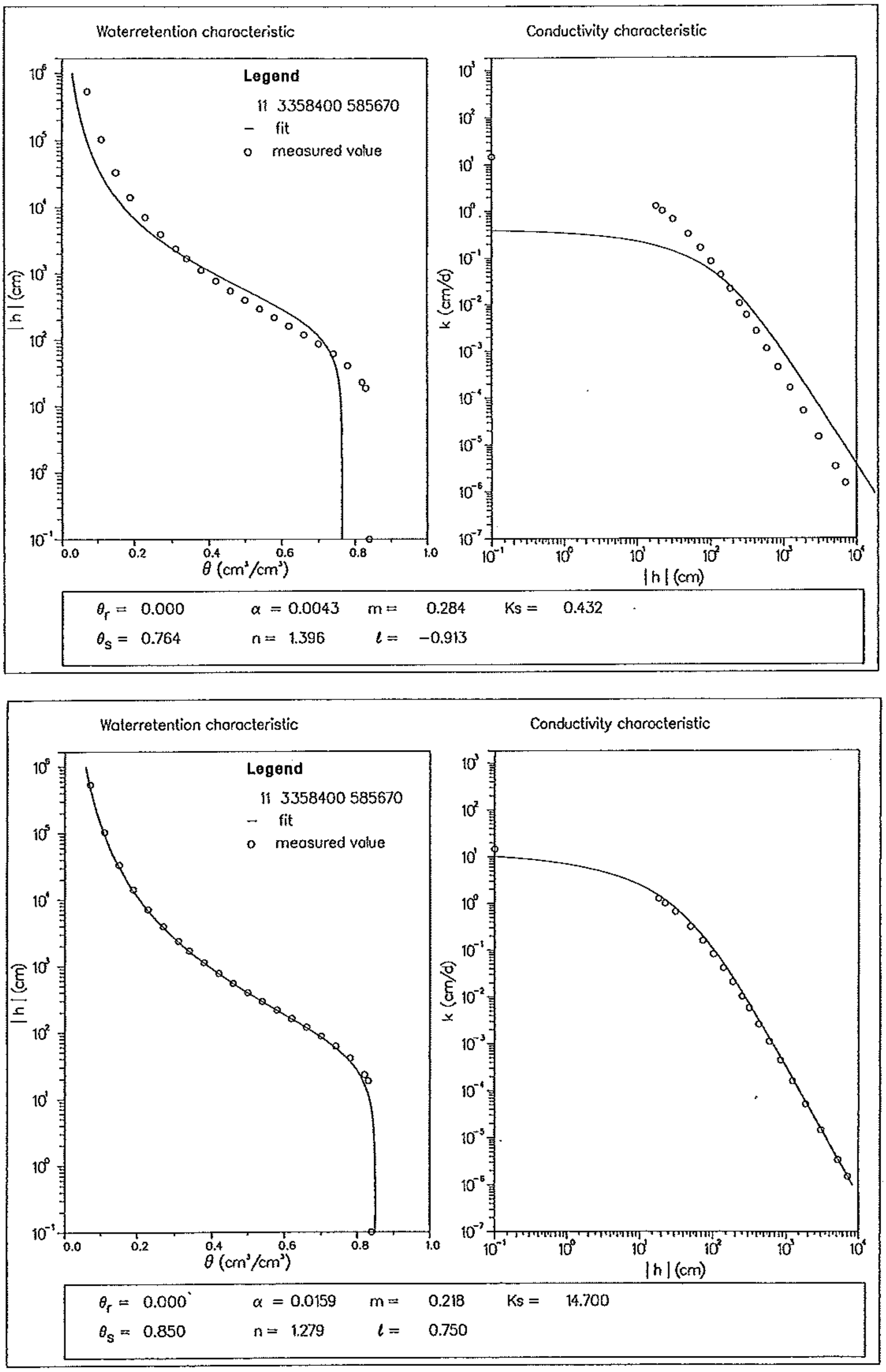


Fig. 11 Initial (a) and final (b) RETC fits, before and after model parameters have been optimized

Table 8 Summary of available measured data

	Soil texture	Total	Processed	With K-data
Topsoils	coarse	510	392	124
	medium	644	463	131
	medium-fine	208	187	93
	fine	217	144	44
	very fine	21	15	6
Subsoils	coarse	947	733	227
	medium	1181	868	179
	medium-fine	520	448	84
	fine	596	517	89
	very fine	132	121	31
	organic*	148	142	128
	Sum	5124	4030	1136

* Within the organic soils no distinction is made in topsoils and subsoils

Table 8 shows the total number of soil horizons for the different categories. In total HYPRES comprises soil information on 5521 soil horizons. There was insufficient information to classify 397 of these into one of the 11 texture classes. Of the remaining 5124 horizons, 4030 could be processed using the Mualem-van Genuchten parameters (including those with no textural data). A total of 1136 horizons had information on both water retention and hydraulic conductivity and 2894 horizons had only information on water retention and not on hydraulic conductivity. As a result, about 80% of the total available data where soil texture class was known were processed and used to derive the pedotransfer functions. Measured unsaturated hydraulic conductivity data was only available for about 28% of these horizons, however, this is still more than 1100 horizons. In general, less measured data are available for the very-fine and fine textured groups as compared to the coarse textured groups.

Once the parameterisation was completed, the optimised Mualen - van Genuchten model parameters were used to generate water content and hydraulic conductivity values for a number of selected pressure head values. The following 14 pressure head values are used in this study 0, -10, -20, -50, -100, -200, -250, -500, -1000, -2000, -5000, -10000, -15000 and -16000 cm. In this way all soil horizons, regardless of the number of original measured data points, could be represented by an equal weight in the process of development of class pedotransfer functions. The derived data are stored in the HYDRAULIC_PROPS table.

3.3.4 Inclusion of data of other formats

Some institutions contributed data in formats other than measured data pairs of the hydraulic characteristics. Omitting these data would have meant a considerable loss of useful information. In a few cases information on soil hydraulic characteristics was given as a set of parameters derived from the same RETC model. In these cases only the model parameters were stored (in the SOIL_PROPS Table). It was assumed that they have been optimised using the same procedure as was applied to the other data. In other cases, replicate samples were taken from the same soil horizon and parameterised datasets were contributed. Here, the RETC program was used to generate quasi-measured data of both water content and hydraulic conductivity at 14 standard pressure heads. These individual values were then averaged thus generating a single set of 'measured data', which was subsequently parameterised with the RETC model. Other data were received in a parameterised form using a model proposed by Davidson et al. (1969). This model assumes an exponential relationship between K and θ. Since the parameters of this model could not simply be matched with the parameters of the Mualem-van Genuchten model, quasi-measured points were generated with the Davidson model, then these data points were parameterised with the Mualem-van Genuchten model.

In a number of cases, no measured hydraulic conductivity data were available, or the number of data pairs was not sufficient, for example, where only saturated hydraulic conductivity was measured. As a consequence, simultaneous fit of the water retention and hydraulic conductivity curves was not possible. Where this occurred, the RETC program was used solely to parameterise the water retention curve. Therefore, neither the parameter l nor K_s were derived.

4 Development of pedotransfer functions

4.1 Introduction

The primary aim of the project was to derive pedotransfer functions capable of predicting the hydraulic properties of soils for which there are no measured data. The preceding chapters described the steps that were taken in order to derive datasets suitable for this purpose.

The first set of pedotransfer functions to be derived were based on the 11 texture/pedological classes which accord with the soil textural information held within the Soil Geographical Data Base associated with the 1: 1 000 000 digital soil map. These pedotransfer functions are called class pedotransfer functions as they predict the average hydraulic characteristics for a soil texture class. The second set of pedotransfer functions are essentially a series of regression equations where the dependant data were the individual soil particle-size fractions, the organic matter content and dry bulk density which were regressed against transformed Mualem-van Genuchten parameters. These pedotransfer functions are called continuous pedotransfer functions as they predict the hydraulic characteristics for a specific soil with known texture, organic matter content and bulk density.

4.2 Class pedotransfer functions

Class pedotransfer functions were derived by firstly using the optimised Mualem-van Genuchten parameters to determine the moisture contents and conductivities at 14 pressure heads as described in Section 3.3.3. These derived soil moisture retention $\theta(h)$ and hydraulic conductivity $K(h)$ curves, which represent the hydraulic characteristics for each individually measured soil horizon, were then grouped into one of the 11 texture/pedological classes described above. Figure 12 shows the individually measured hydraulic characteristics for the medium-fine textured topsoils. Visual inspection of the individual characteristics for each texture class allows identification of outliers. These outliers were omitted from further analysis.

As the $\theta(h)$ and $K(h)$ relationships are lognormally distributed, the geometric mean moisture content and conductivity at the 14 pressure heads were calculated. In addition to the mean values, the θ and K values within one standard deviation were calculated for the same 14 values of pressure head. These standard deviations give an indication of the degree of variation of the individual curves around the geometric mean curve, see for example Figure 13. This procedure results in values for moisture contents and conductivities at 14 different pressure heads from saturation to around permanent wilting point (0 to -16000 cm). However, many simulation models require these data in the form of Mualem-van Genuchten equations, therefore, the 14 mean values were again parameterised to give typical values for the seven parameters for each of the 11 texture classes (Table 9).

Table 10 Moisture contents and conductivities at 14 pressure heads using the optimised Mualem – van Genuchten parameters

TOPSOILS	texture class	h (cm)	0	10	20	50	100	200	250	500	1000	2000	5000	10000	15000	16000
		pF	0	1	1.3	1.7	2	2.3	2.4	2.7	3	3.3	3.7	4	4.17	4.2
	coarse	K	60.00	6.68	2.37	0.31	4.7E-2	5.8E-3	2.8E-3	3.2E-4	3.5E-5	3.8E-6	1.9E-7	2.1E-8	5.9E-9	4.7E-9
		θ	0.403	0.379	0.352	0.294	0.243	0.197	0.184	0.148	0.12	0.098	0.077	0.065	0.06	0.059
	medium	K	12.10	0.61	0.29	0.08	2.5E-2	7.4E-3	4.8E-3	1.3E-3	3.5E-4	9.2E-5	1.6E-5	4.1E-6	1.9E-6	1.7E-6
		θ	0.439	0.425	0.41	0.379	0.347	0.313	0.302	0.27	0.24	0.213	0.182	0.162	0.152	0.15
	medium-fine	K	2.27	0.51	0.33	0.14	5.7E-2	1.8E-2	1.1E-2	2.7E-3	5.9E-4	1.2E-4	1.4E-5	2.8E-6	1.1E-6	9.3E-7
		θ	0.43	0.426	0.421	0.406	0.383	0.349	0.336	0.293	0.252	0.215	0.173	0.147	0.134	0.132
	fine	K	24.80	0.38	0.16	0.04	1.3E-2	3.5E-3	2.3E-3	5.9E-4	1.5E-4	3.8E-5	6.1E-6	1.5E-6	7.0E-7	6.1E-7
		θ	0.52	0.507	0.495	0.472	0.448	0.423	0.414	0.388	0.364	0.34	0.311	0.291	0.28	0.278
	very fine	K	15.00	0.30	0.13	0.03	8.0E-3	1.8E-3	1.1E-3	2.1E-4	3.9E-5	7.3E-6	7.6E-7	1.4E-7	5.3E-8	4.5E-8
		θ	0.614	0.602	0.592	0.567	0.541	0.511	0.501	0.47	0.439	0.41	0.374	0.349	0.336	0.334
SUBSOILS	texture class	h (cm)	0	10	20	50	100	200	250	500	1000	2000	5000	10000	15000	16000
		pF	0	1	1.3	1.7	2	2.3	2.4	2.7	3	3.3	3.7	4	4.17	4.2
	coarse	K	70.00	10.50	3.24	0.30	3.1E-2	2.7E-3	1.2E-3	9.6E-5	7.6E-6	6.0E-7	2.0E-8	1.6E-9	3.7E-10	2.9E-10
		θ	0.366	0.338	0.304	0.233	0.179	0.135	0.123	0.094	0.073	0.059	0.046	0.039	0.037	0.036
	medium	K	10.80	0.58	0.28	0.07	2.2E-2	5.6E-3	3.5E-3	8.0E-4	1.8E-4	3.9E-5	5.2E-6	1.1E-6	4.7E-7	4.1E-7
		θ	0.392	0.382	0.372	0.349	0.324	0.296	0.286	0.258	0.231	0.207	0.179	0.16	0.151	0.149
	medium-fine	K	4.00	0.72	0.45	0.19	7.1E-2	2.1E-2	1.3E-2	2.8E-3	5.5E-4	1.0E-4	9.9E-6	1.7E-6	6.4E-7	5.3E-7
		θ	0.412	0.409	0.405	0.392	0.373	0.344	0.333	0.297	0.261	0.227	0.189	0.164	0.151	0.149
	fine	K	8.47	0.18	0.09	0.03	1.1E-2	3.6E-3	2.4E-3	7.1E-4	2.1E-4	5.8E-5	1.1E-5	3.0E-6	1.4E-6	1.3E-6
		θ	0.481	0.475	0.47	0.456	0.441	0.422	0.415	0.394	0.373	0.353	0.327	0.309	0.299	0.297
	very fine	K	8.16	0.14	0.07	0.02	7.6E-3	2.2E-3	1.4E-3	3.5E-4	8.5E-5	2.0E-5	2.8E-6	6.4E-7	2.8E-7	2.4E-7
		θ	0.538	0.533	0.529	0.517	0.503	0.486	0.479	0.459	0.438	0.418	0.392	0.373	0.363	0.361
	organic*	K	8.00	0.97	0.55	0.18	5.9E-2	1.5E-2	9.2E-3	1.9E-3	3.7E-4	6.8E-5	6.9E-6	1.3E-6	4.7E-7	4.0E-7
		θ	0.766	0.756	0.743	0.708	0.663	0.604	0.583	0.517	0.455	0.398	0.332	0.29	0.269	0.265

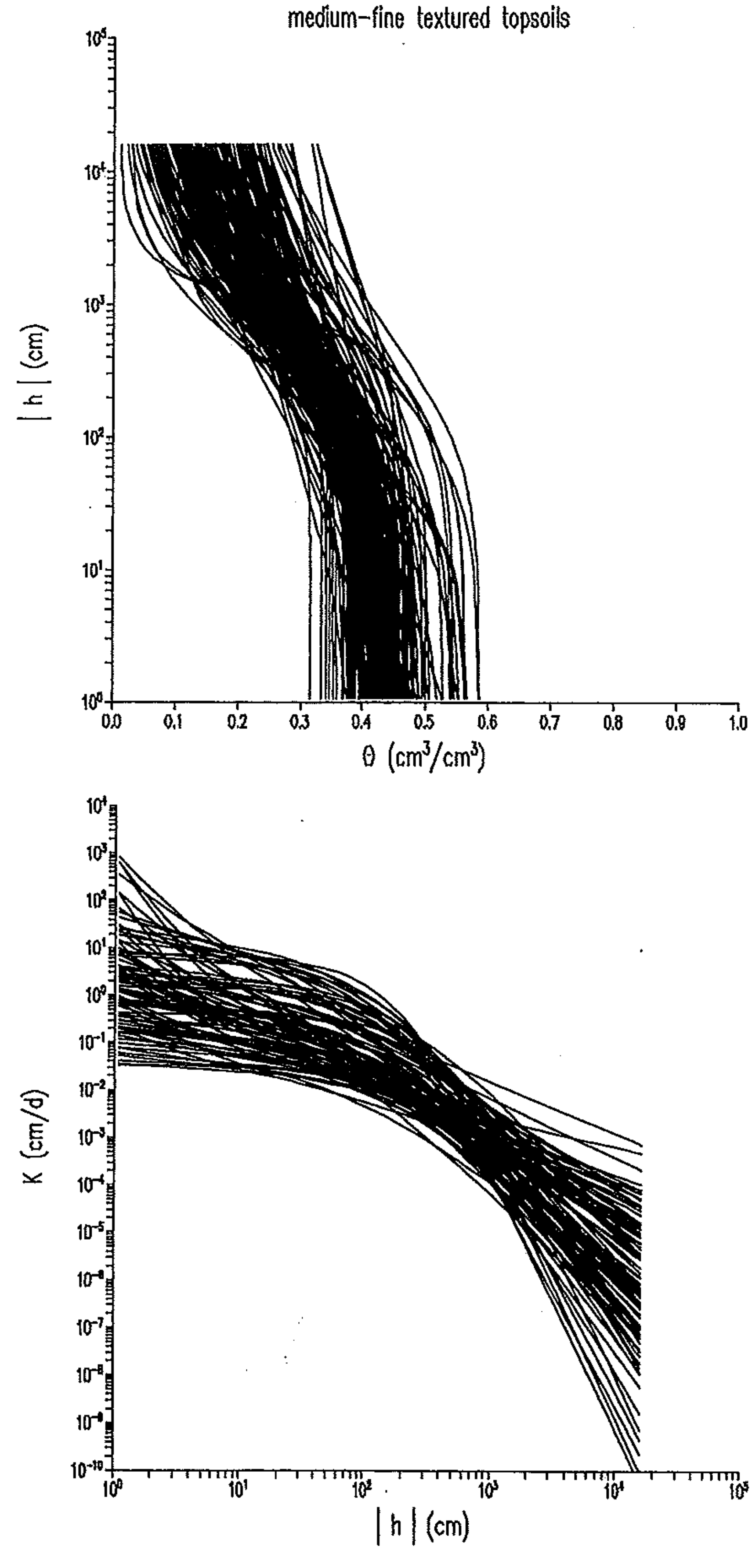


Fig. 12 Individually measured hydraulic characteristics for the medium-fine textured topsoils

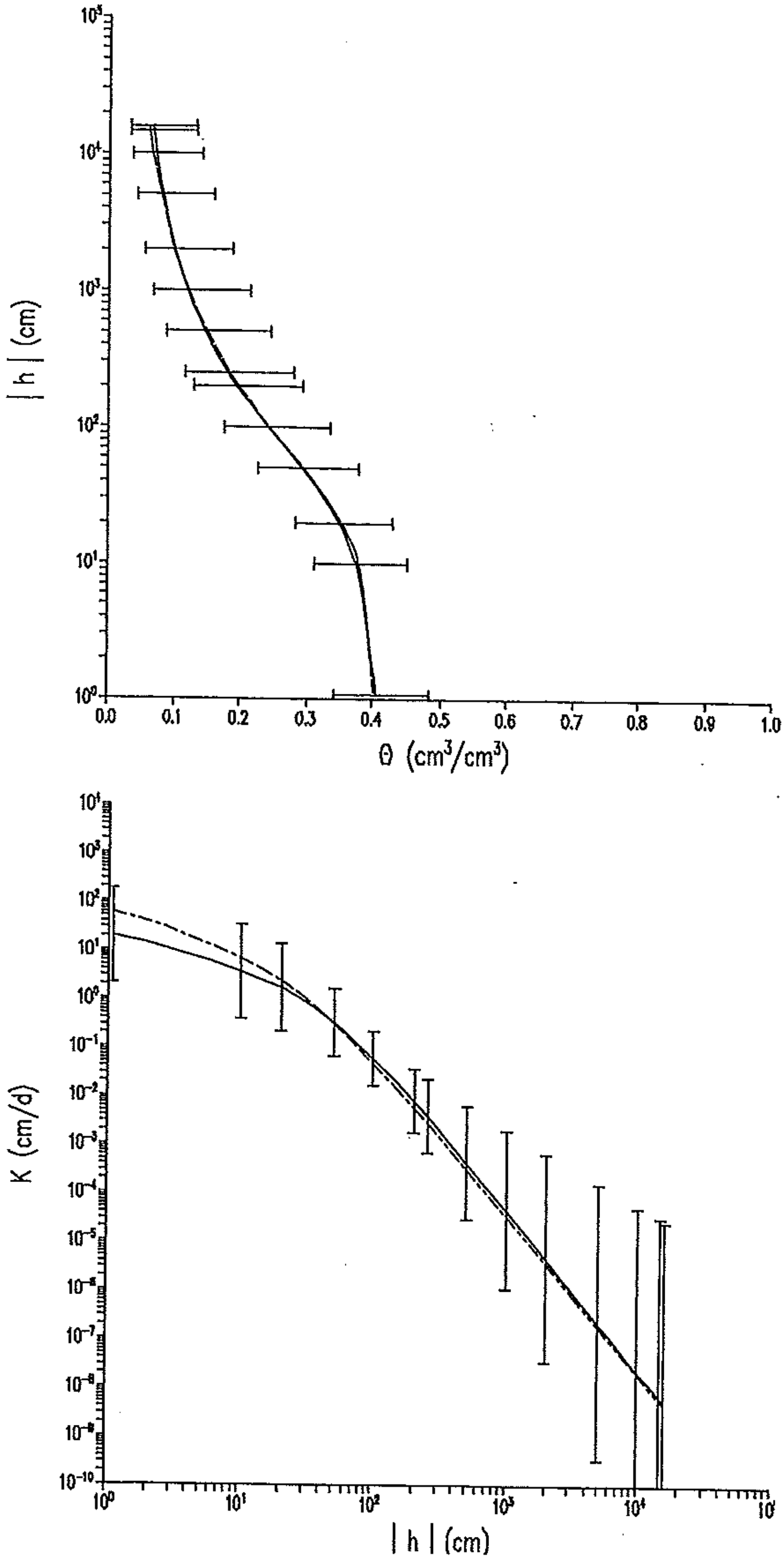
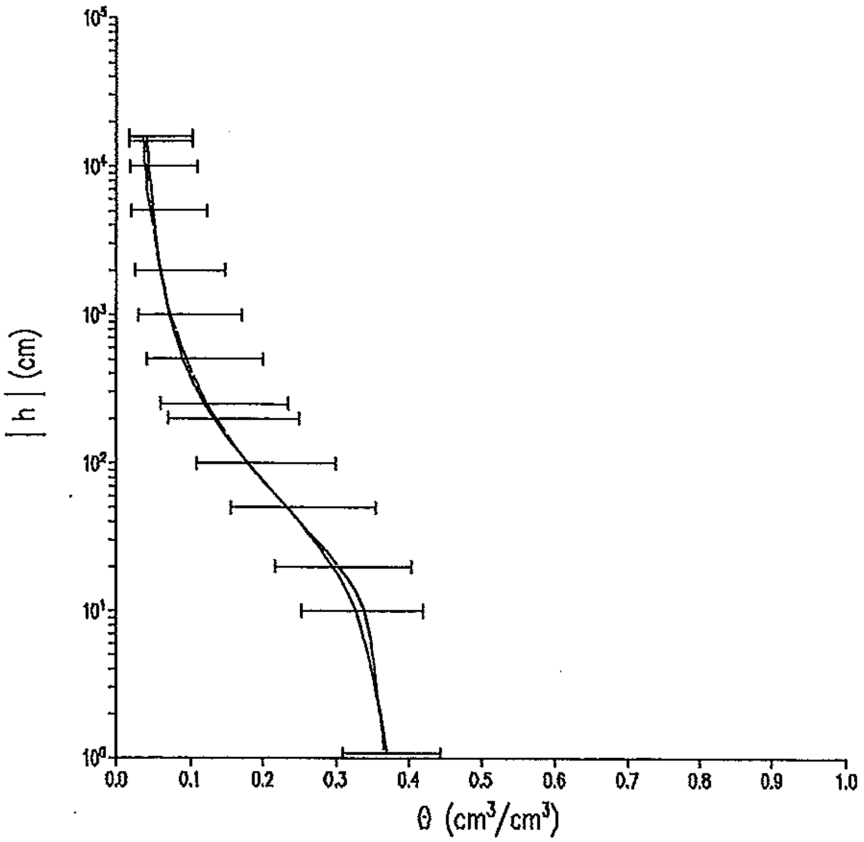


Fig. 13a Coarse textured topsoils

The Figures 13 Calculated geometric mean water retention (upper graph) and hydraulic conductivity (lower graph) characteristics (solid lines) and the standard deviations for each of the 11 texture groups (bars). The Mualem-van Genuchten fit to the geometric mean values are shown as a dotted line.



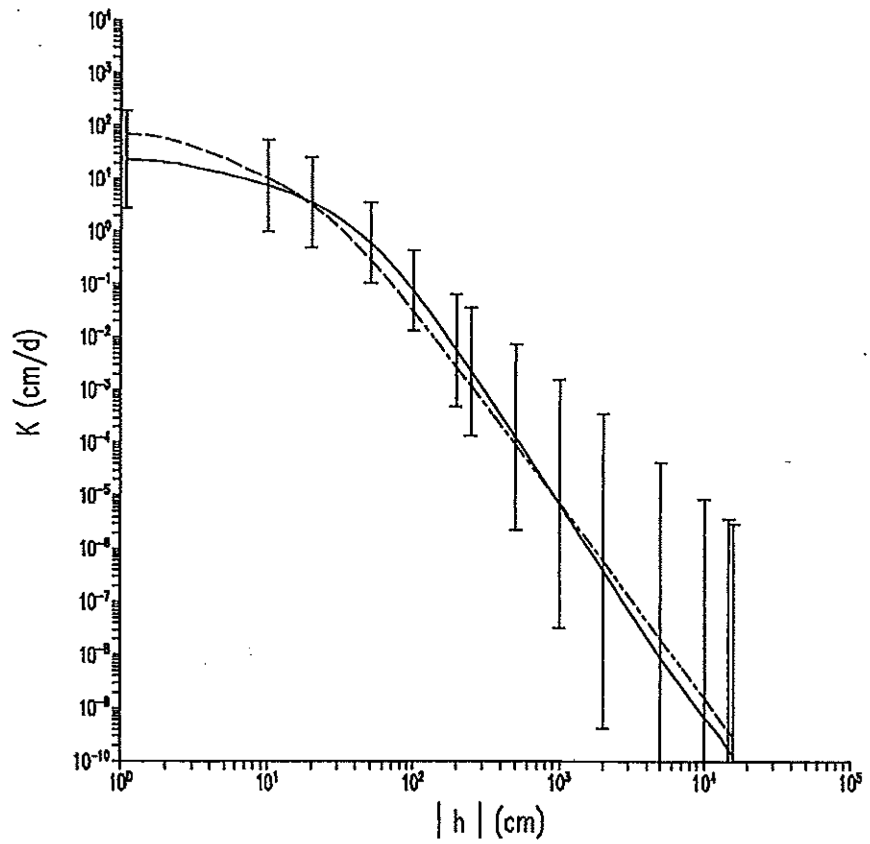
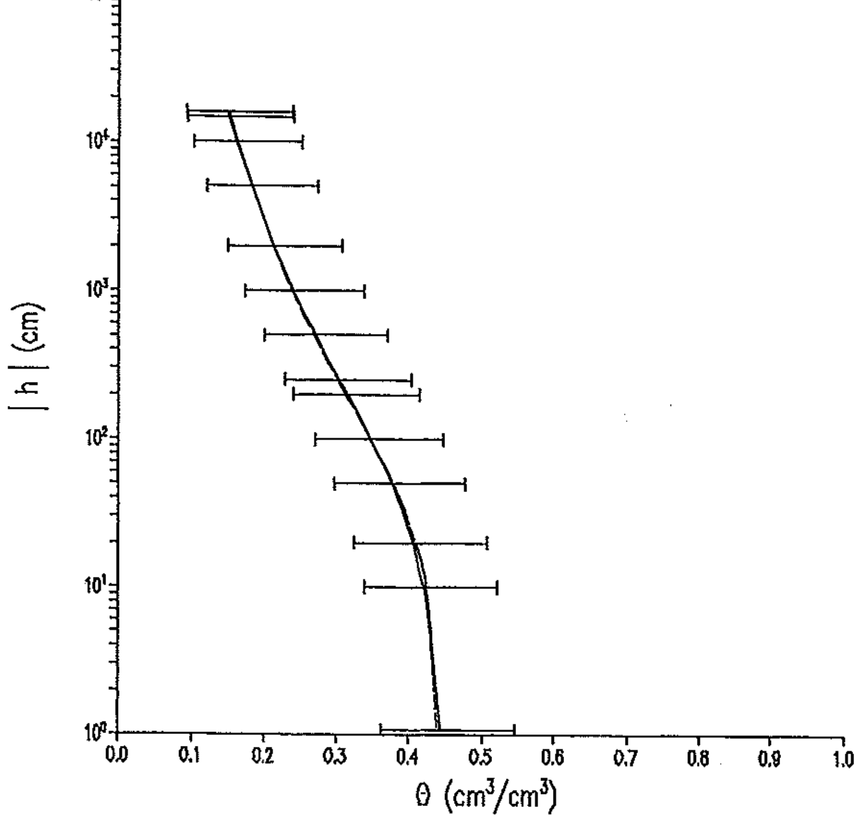


Fig. 13b Coarse textured subsoils



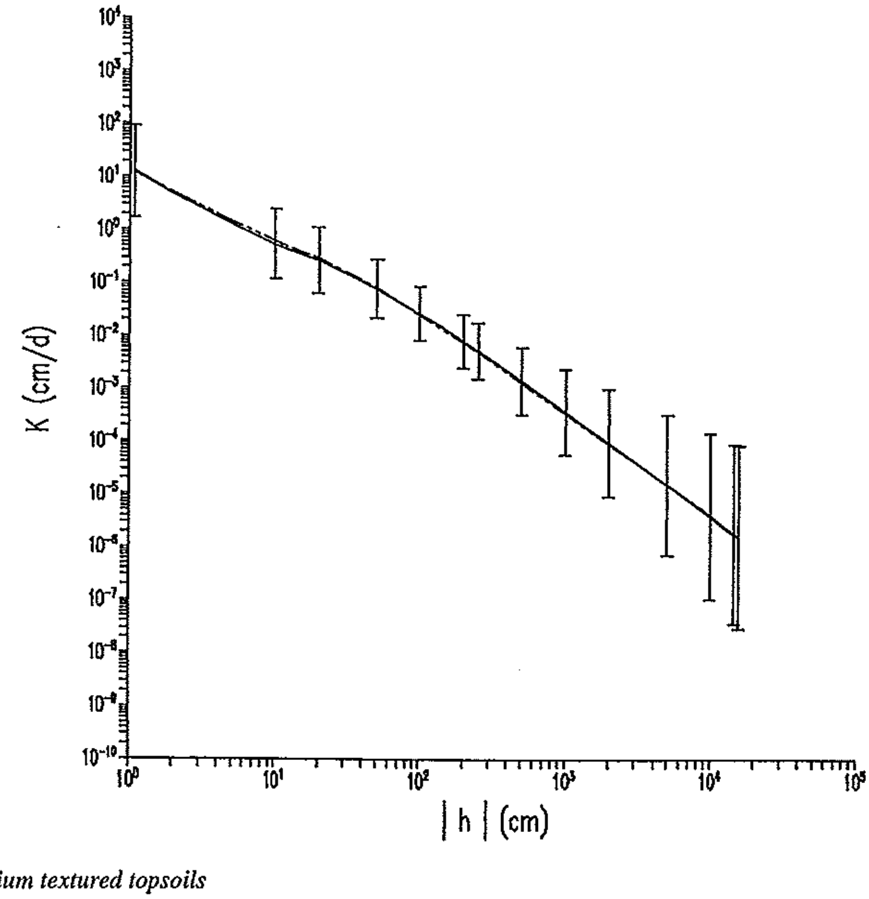


Fig. 13c Medium textured topsoils

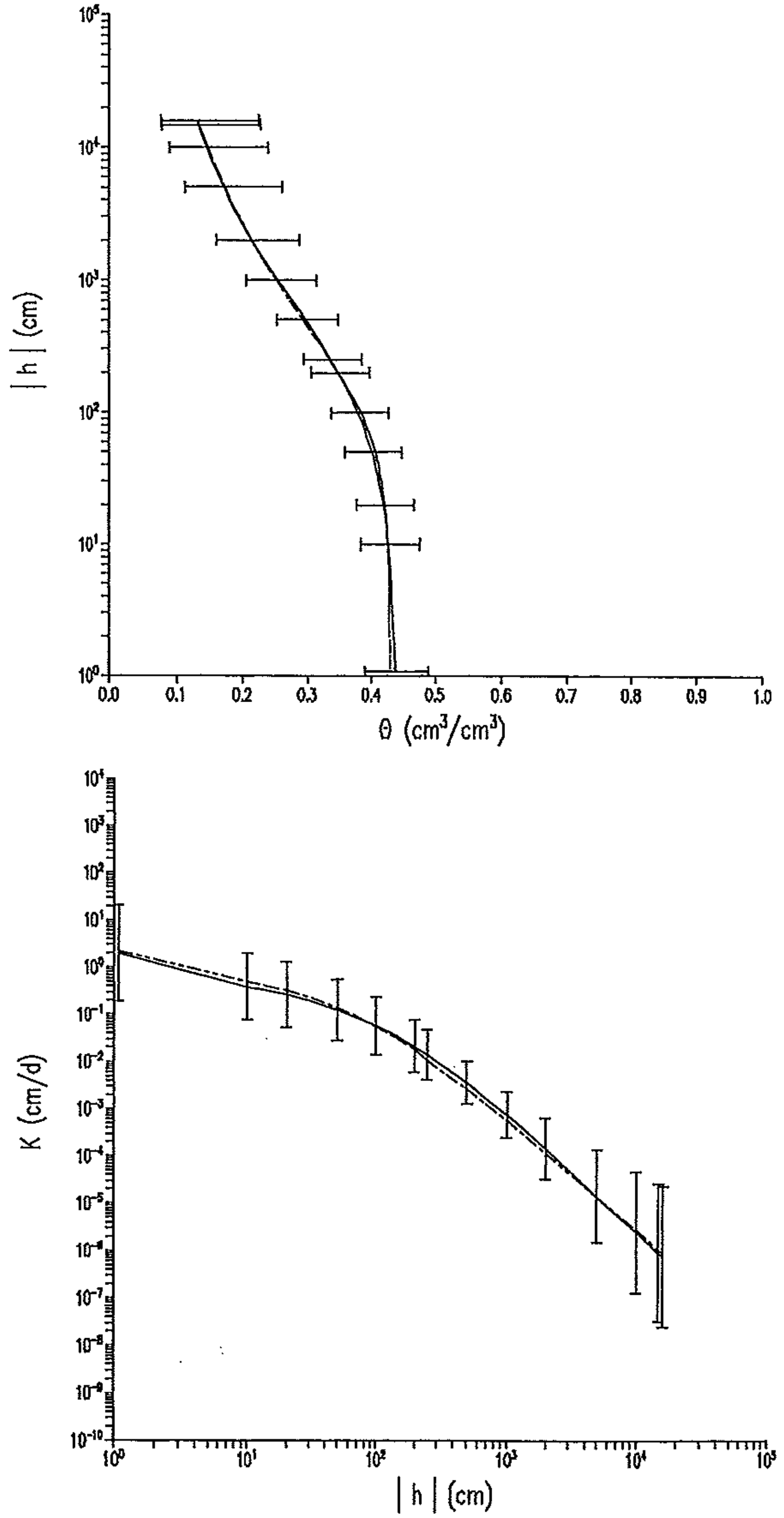


Fig. 13d Medium textured subsoils

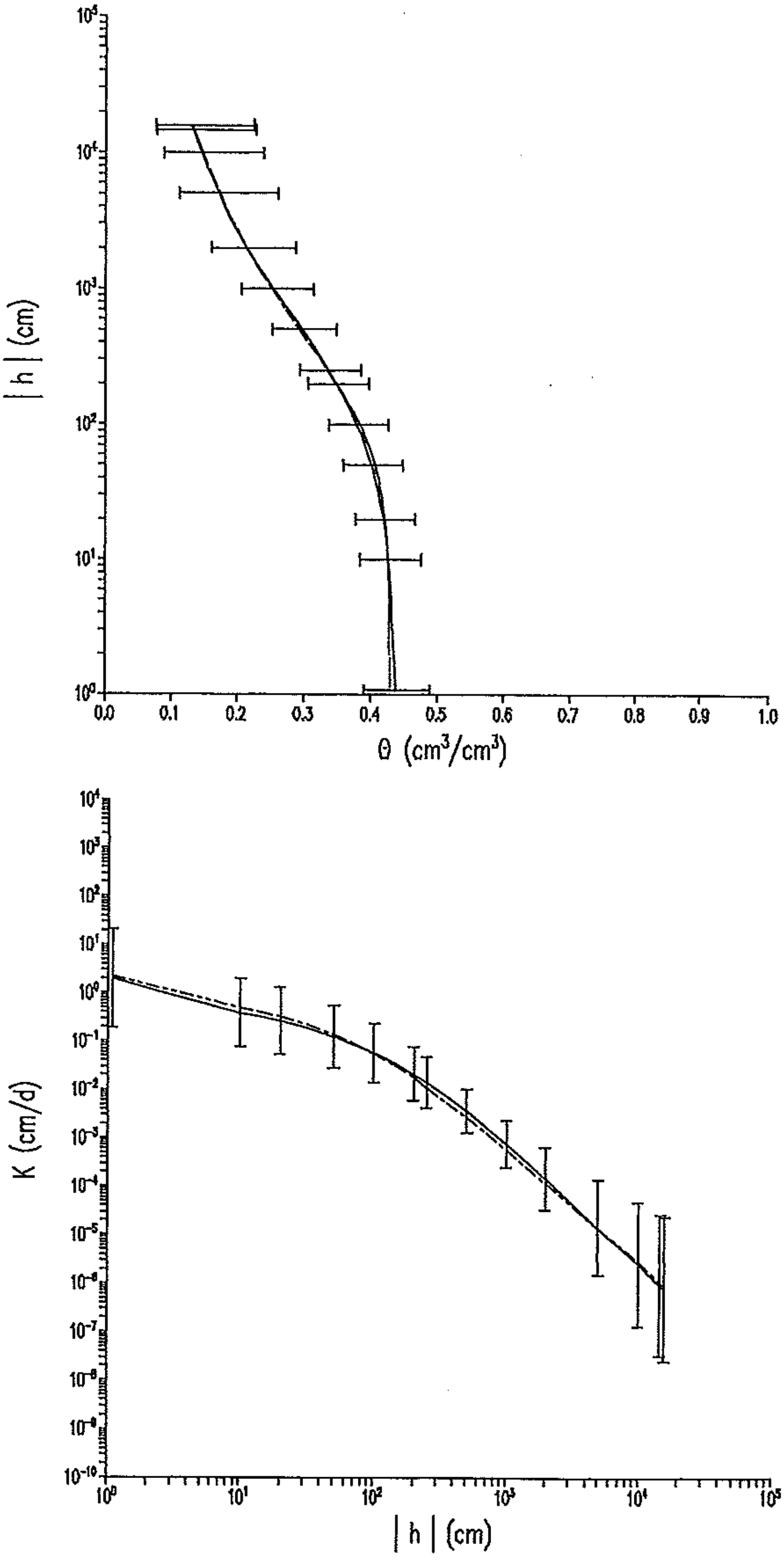
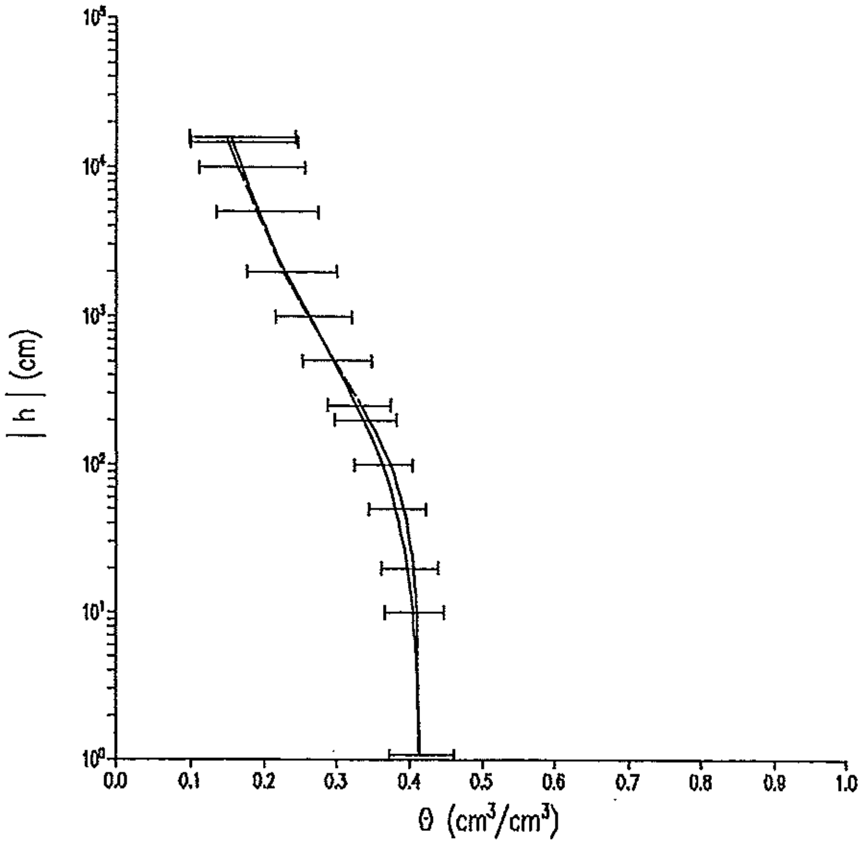


Fig. 13e Medium-fine textured topsoils



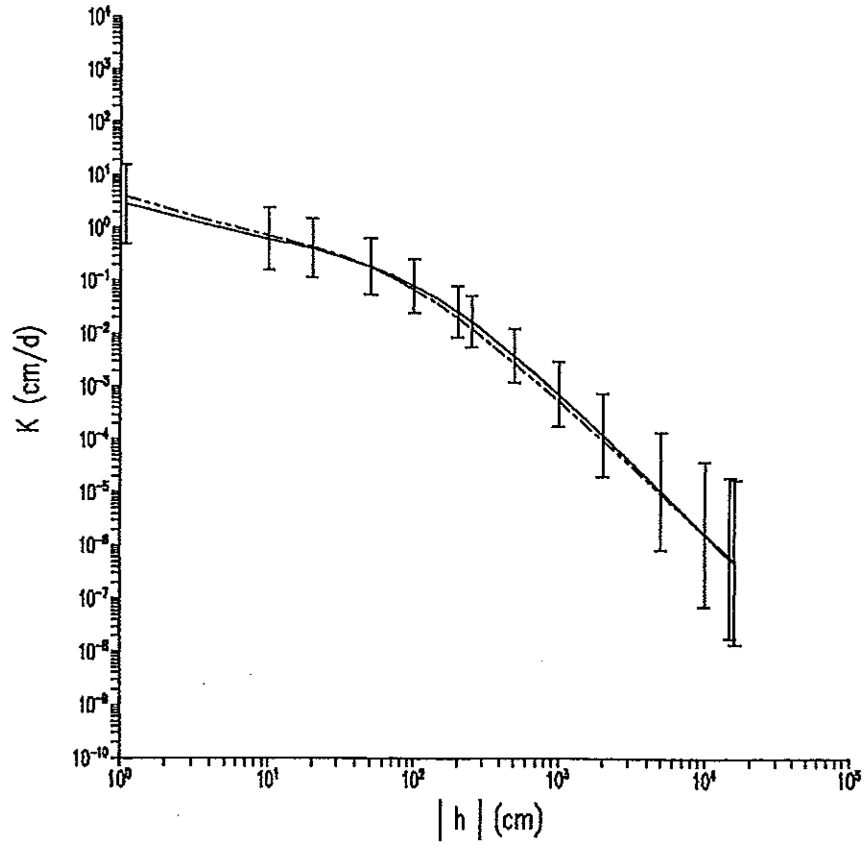


Fig. 13f Medium-fine textured subsoils

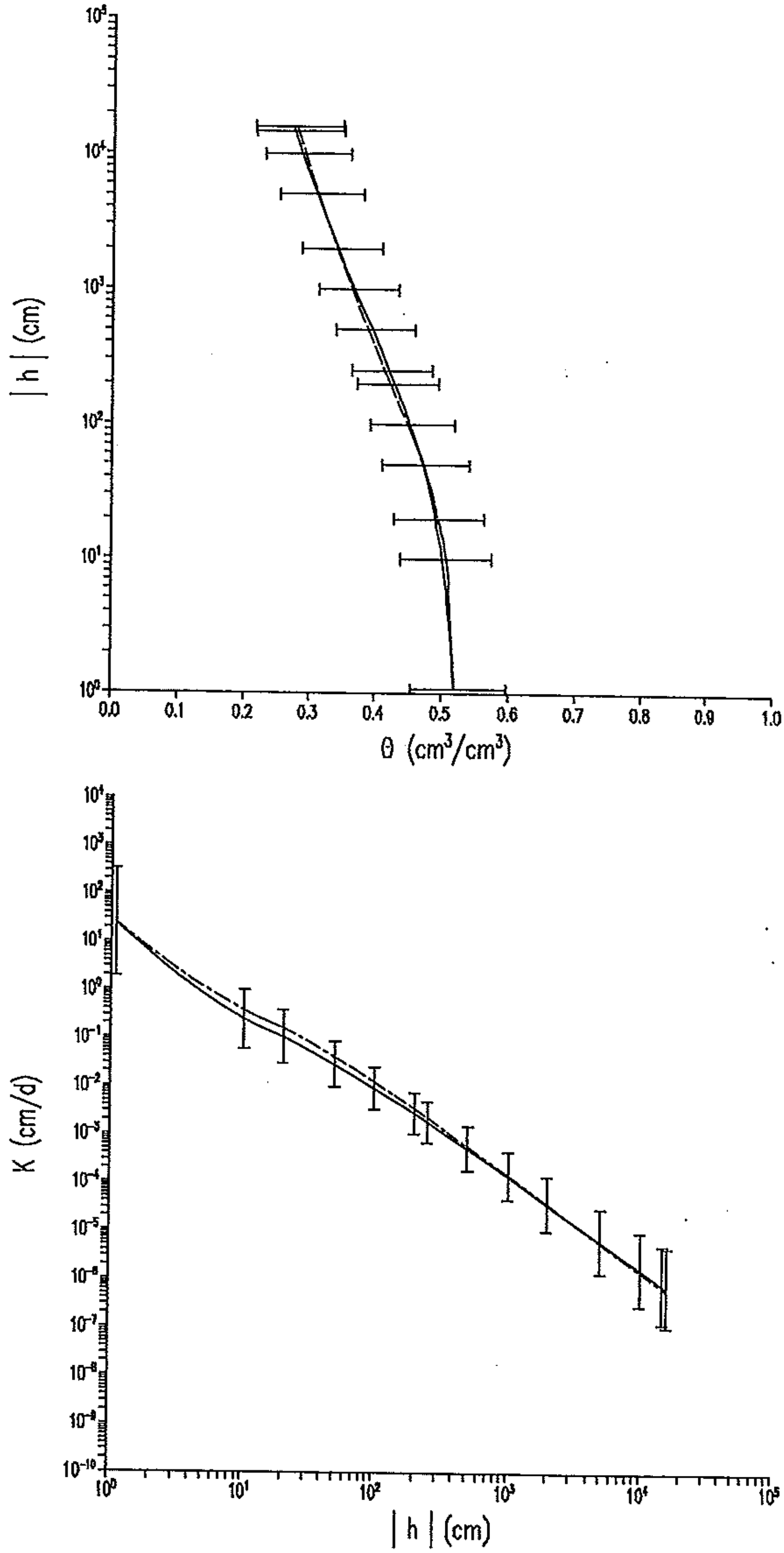
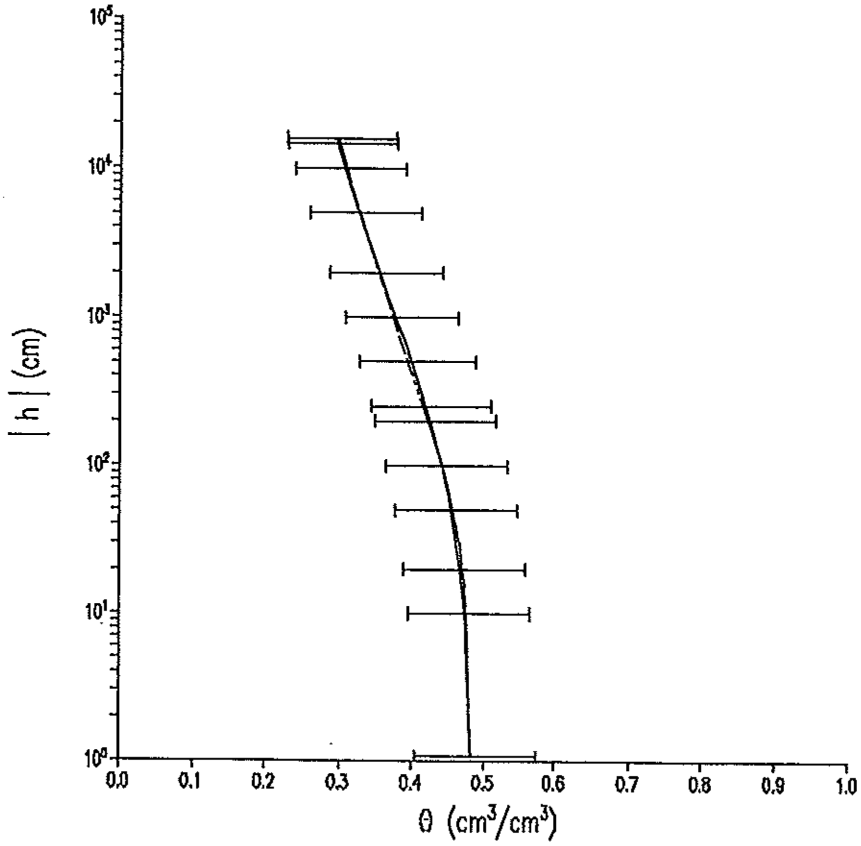


Fig. 13g Fine textured topsoils



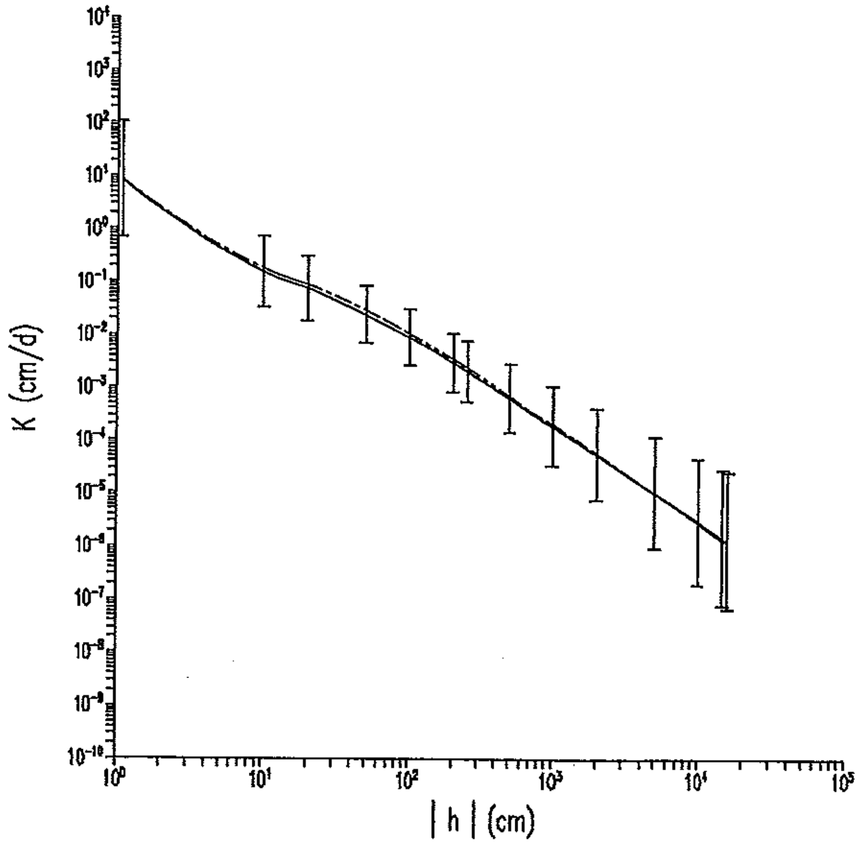


Fig. 13h Fine textured subsoils

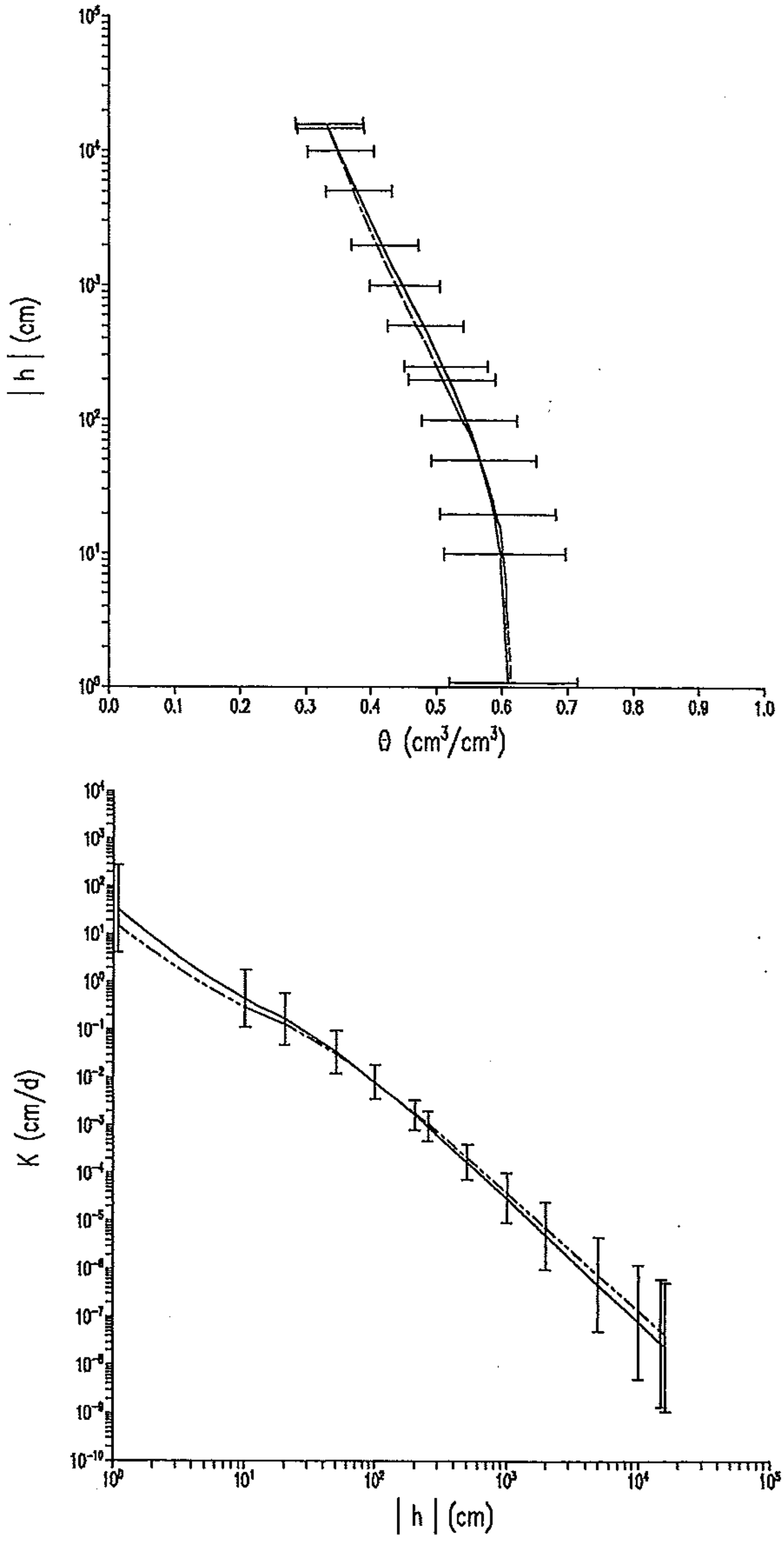
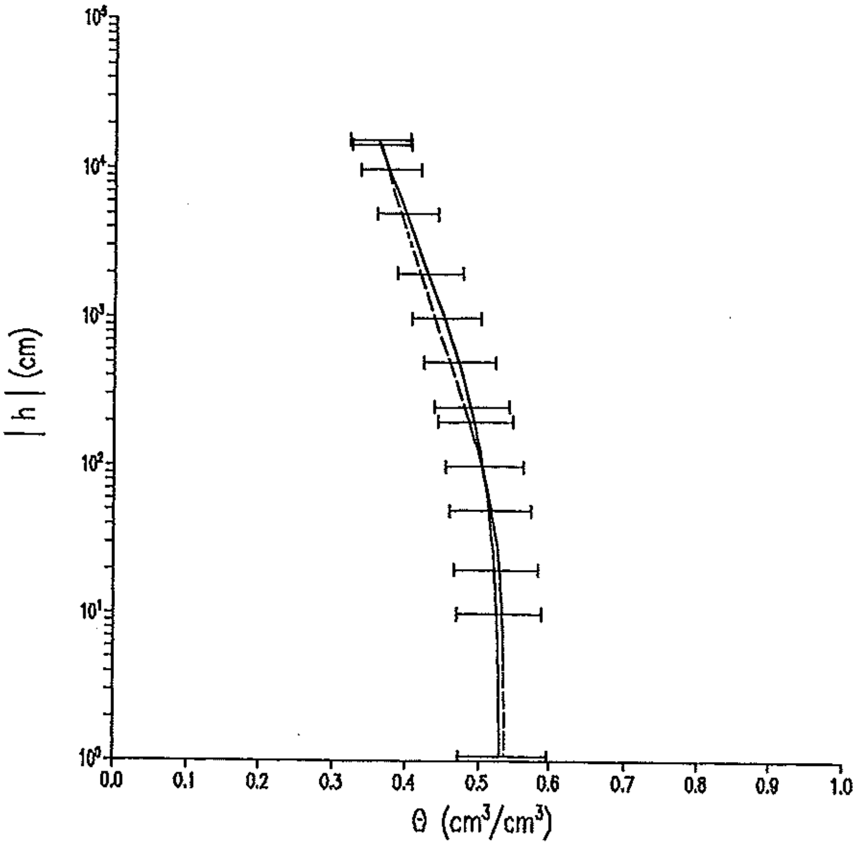


Fig. 13i Very fine textured topsoils



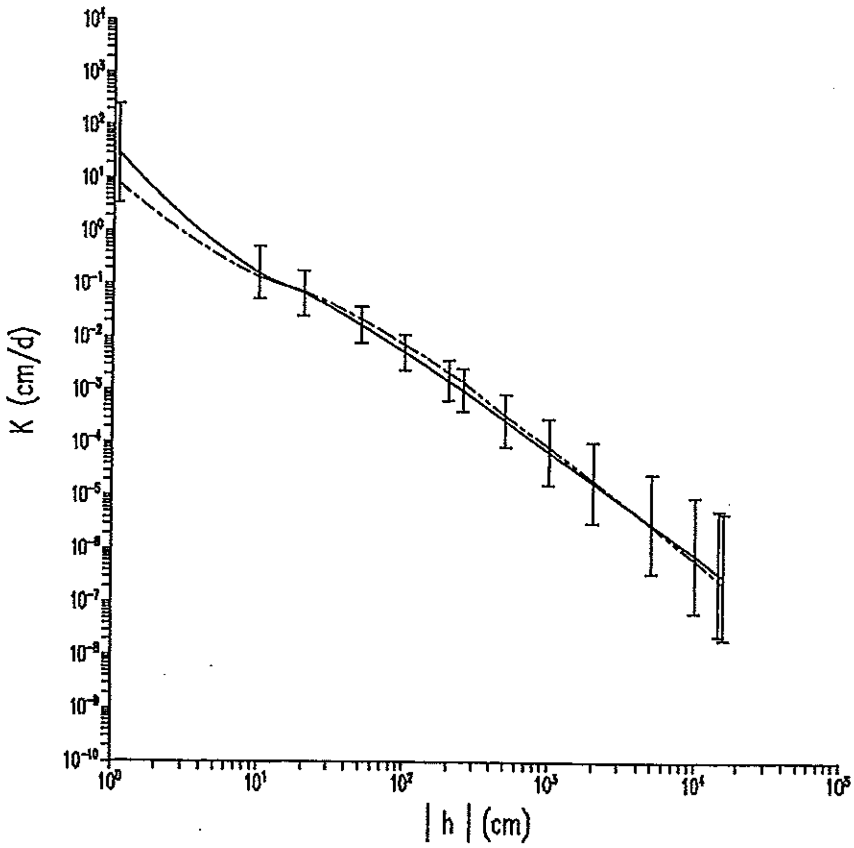


Fig. 13j Very fine textured subsoils

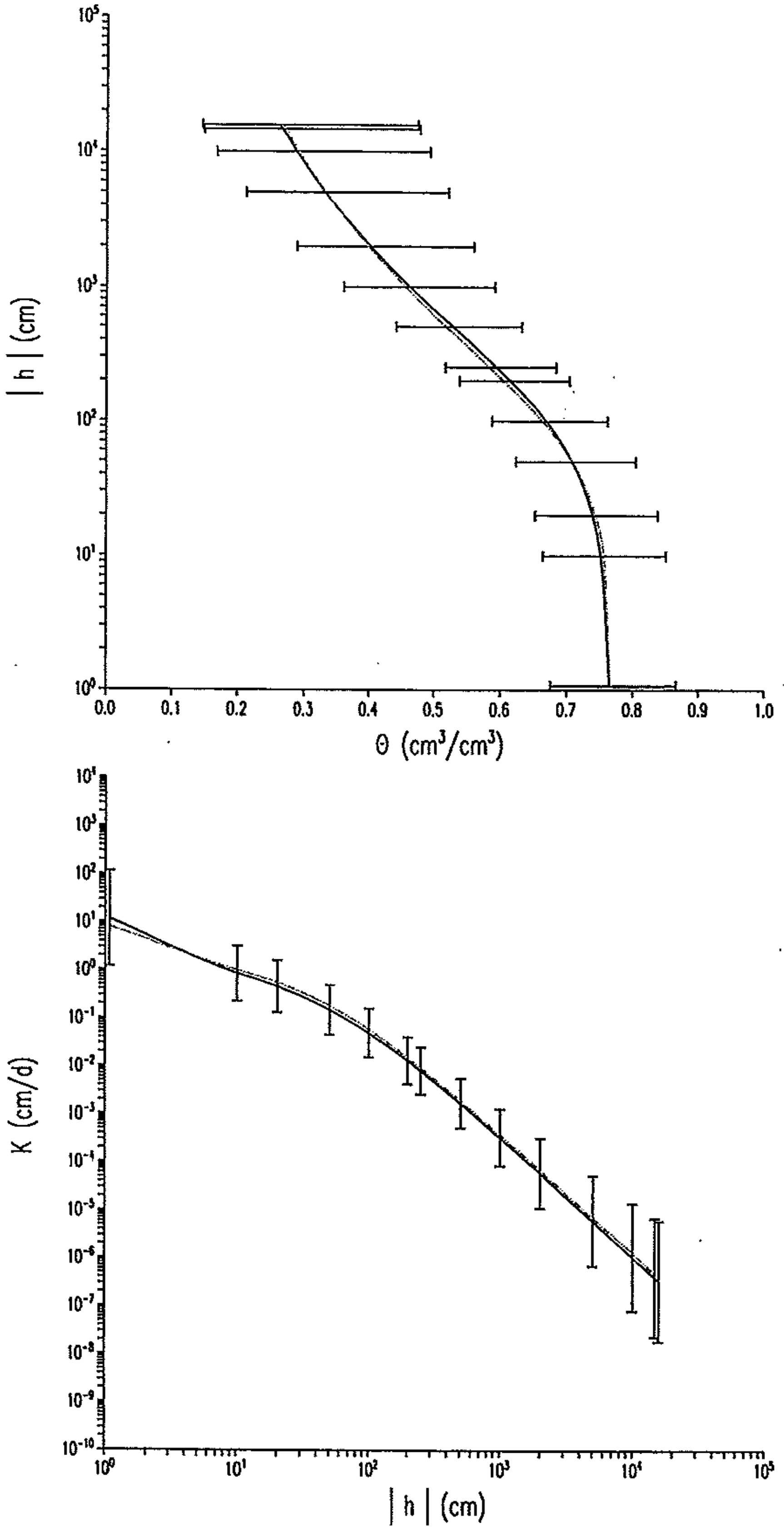


Fig. 13k Organic layers (histic)

4.3 Continuous pedotransfer functions

Early forms of continuous pedotransfer functions were regression equations that predicted specific points of interest of the water retention and hydraulic conductivity characteristic (Ahuja et al., 1985). Consequently these functions often have the following form:

θ_{100} = a + b*clay + c*organic matter + d* dry bulk density +.....x*variable

where a, b, c, d and x are constants.

A disadvantage of this approach is that many different regressions have to be performed in order to quantify the soil moisture retention characteristic and that the output tends to be tabular. This format is generally of more limited use in simulation models. An alternative approach is to regress the parameters of the Mualem-van Genuchten model against similar, easily determined data such as texture, organic matter content and bulk density (Wösten et al. 1995). This latter approach can be more efficient than the point-prediction procedure.

To derive continuous pedotransfer functions for the HYPRES database linear regression was used to investigate the dependency of each model parameter on more easily measured basic soil properties. To comply with a number of physical boundary conditions, transformed parameters rather than the original model parameters are used in the regression analysis. In this case, the imposed boundary conditions are: $K_s > 0$, $a > 0$, $n > 1$ and $-10 < l < +10$. As a consequence, parameters are transformed as follows; $K_s^* = \ln(K_s)$, $a^* = \ln(a)$, $n^* = \ln(n\text{-}1)$ and $l^* = \ln((l+10) / (10\text{-}l))$. The following basic soil properties are used as regressed variables: percent clay, percent silt, percent organic matter; bulk density and also the qualitative variable topsoil or subsoil.

Linear, reciprocal, and exponential relationships of these basic soil properties are used in the regression analysis, and possible interactions are also investigated. As a consequence, the resulting regression model or continuous pedotransfer function consists of various basic soil properties and their interactions, all of which contribute significantly to the description of the transformed model parameters. This model is selected with the subset selection method of Furnival and Wilson (1974). The resulting continuous pedotransfer functions are presented in Table 11. After prediction of the transformed model parameters with these functions, the hydraulic characteristics are obtained by back-transformation to the original model parameters.

θ_s is a model parameter, α^*, n^*, l^* and K_s^* are transformed model parameters in the Mualem-van Genuchten equations; C = percent clay (i.e. percent < 2 μm); S = percent silt (i.e. percent between 2 μm and 50 μm); OM = percent organic matter; D = bulk density; topsoil and subsoil are qualitative variables having the value of 1 or 0 and ln = natural logarithm.

Table 11 Continuous pedotransfer functions for the prediction of hydraulic characteristics

θ_s = 0.7919 + 0.001691*C – 0.29619*D – 0.000001491*S^2 + 0.0000821*OM^2 + 0.02427*C^{-1} + 0.01113*S^{-1} + 0.01472*ln(S) – 0.0000733*OM*C – 0.000619*D*C – 0.001183*D*OM – 0.0001664*topsoil*S
(R^2 = 76%)

α* = -14.96 + 0.03135*C + 0.0351*S + 0.646*OM +15.29*D – 0.192*topsoil – 4.671*D^2 – 0.000781*C^2 – 0.00687*OM^2 + 0.0449*OM^{-1} + 0.0663*ln(S) + 0.1482*ln(OM) – 0.04546*D*S – 0.4852*D*OM +0.00673*topsoil*C
(R^2 = 20%)

n* = -25.23 – 0.02195*C + 0.0074*S – 0.1940*OM + 45.5*D – 7.24*D^2 + 0.0003658*C^2 + 0.002885*OM^2 –12.81*D^{-1} – 0.1524*S^{-1} – 0.01958*OM^{-1} – 0.2876*ln(S) – 0.0709*ln(OM) – 44.6*ln(D) – 0.02264*D*C + 0.0896*D*OM + 0.00718*topsoil*C
(R^2 = 54%)

l* = 0.0202 + 0.0006193*C^2 – 0.001136*OM^2 – 0.2316*ln(OM) – 0.03544*D*C + 0.00283*D*S + 0.0488*D*OM
(R^2 = 12%)

K_s* = 7.755 + 0.0352*S + 0.93*topsoil – 0.967*D^2 – 0.000484*C^2 – 0.000322*S^2 + 0.001*S^{-1} – 0.0748*OM^{-1} – 0.643*ln(S) – 0.01398*D*C – 0.1673*D*OM + 0.02986*topsoil*C – 0.03305*topsoil*S
(R^2 = 19%)

4.4 Evaluation of the derived pedotransfer functions

In general, the calculated geometric means and the fitted curves agree very well, except for the saturated hydraulic conductivities (K_s) of the coarse and very fine texture classes. The presence of cracks and macro pores in these soils can cause an incorrect estimation of the saturated conductivities when the Mualem-van Genuchten equations are used. However, the Figures also show that the deviation of the fit on the measured K_s values is well within the range of plus and minus one standard deviation around the measured K_s value.

The class pedotransfer functions comprise geometric mean water retention and hydraulic conductivity characteristics (plus standard deviations) for the 11 soil texture classes or 11 major building blocks, which accord with those used in the 1 : 1 000 000 Soil Geographical Data Base of Europe. The concept of building blocks allows a soil physical interpretation of existing soil maps to be made and thus generates information on the soil physical composition of the unsaturated zone for areas of land (Wösten et al., 1985).

Class pedotransfer functions predict the hydraulic characteristics for rather broadly defined soil texture classes. As a consequence they do not provide site specific information. In contrast, continuous pedotransfer functions are more site specific.

The R^2 values in Table 11 indicate that the predictions of the hydraulic characteristics when using continuous pedotransfer functions are not very accurate. Subdividing the complete dataset in subsets of similar soil texture might improve these predictions. In addition, further analysis should reveal if the inclusion of other properties or the application of neural networks instead of regression are feasible options.

5 Application of the pedotransfer functions at a European scale

5.1 Introduction

Throughout the preceding chapters emphasis has been placed on the fact that, although not part of the original contract, efforts have been made to ensure that the HYPRES database and the derived products were compatible with existing EU-wide soils database and with the 1 : 1 000 000 Soil Geographical Data Base of Europe (Jamagne et al., 1994) in particular. In order to test whether this was indeed true and to present a practical application of the derived pedotransfer functions, links were established with the group in Orléans who currently work on the development of the Soil Geographical Data Base. An advantage of the data in HYPRES is that, for a great many of the profiles, there are accurate georeferences (see the Chapter 2), a disadvantage is that these georeferences are not standardised throughout Europe. The pedotransfer functions were derived with the soil textural classes used in the Soil Geographical Data Base in mind and are therefore fully compatible with this dataset and will add considerably to its usefulness.

To assure that the HYPRES data could be fully integrated with other EU-wide soils databases it was decide to standardise the disparate geo-references to a common system.

5.2 Transformation of the geo-references of the HYPRES data

Several problems were encountered during the transformation of the existing co-ordinates of the data within HYPRES to a common reference system. Although it was expected that co-ordinate systems would vary between countries, it was also found that in some cases, the co-ordinate systems were not homogeneous within countries. Other problems encountered included:

- The use of several different reference systems, for example, the use of alpha-numeric codings (Scotland and Northern Ireland) compared with co-ordinates given in degrees or in numerical form.
- Co-ordinate parameters were initially unknown or difficult to obtain for some specific projection systems used by the institutions.
- The heterogeneity in specified units, for example, most co-ordinates systems use metres but for France they were given in kilometres.
- For some countries, for example, Spain and Portugal, the profiles location with respect to the Greenwich meridian was not specified.
- In some cases the latitude (the y-axis) and longitude (the x-axis) were reversed.

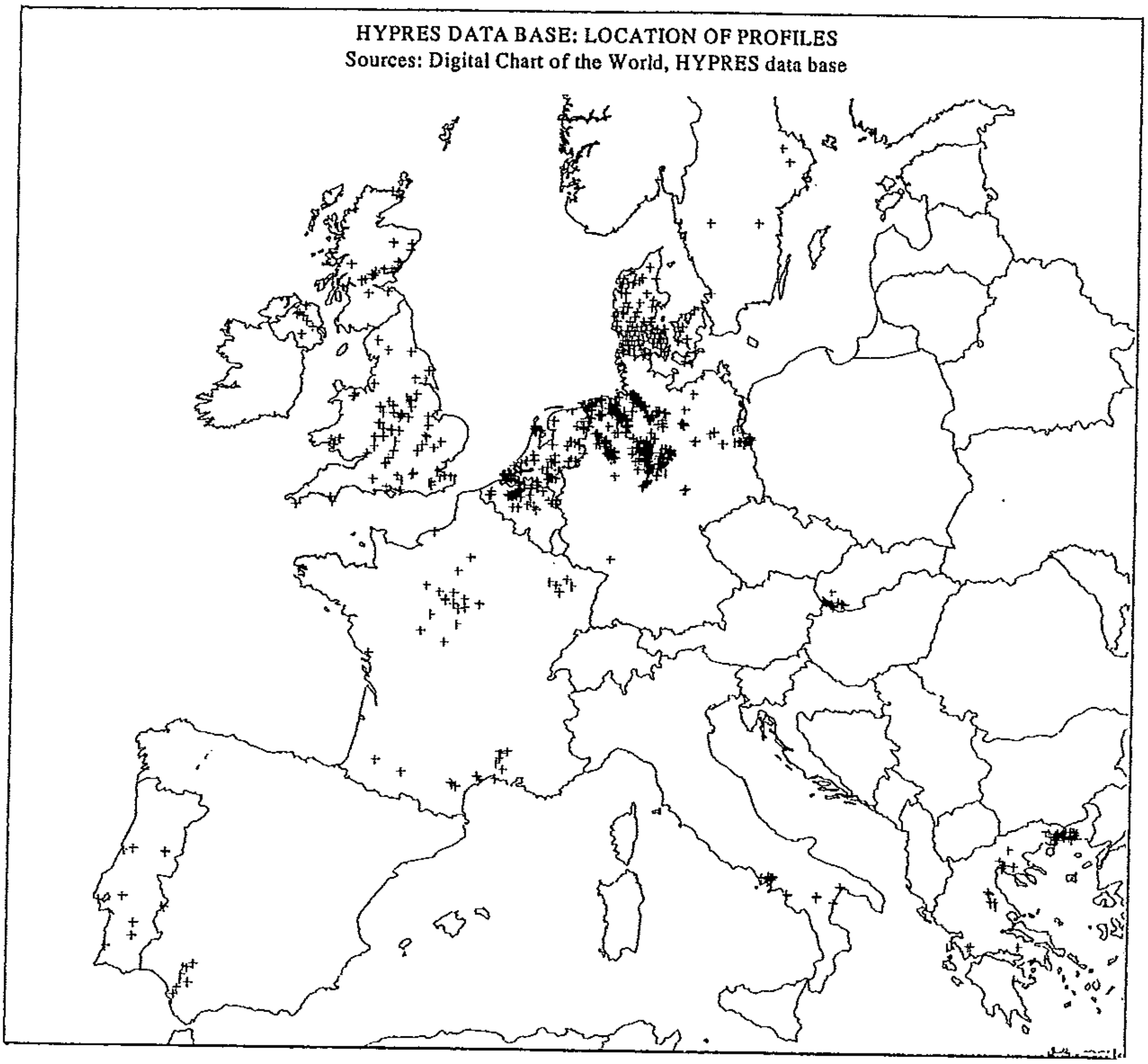


Fig. 14 Location of the profiles held within the HYPRES database

As a consequence, transforming co-ordinates from their original reference system to the common reference system had to be carried out for each individual contributed dataset separately. Several tests were conducted in order to eliminate as many inconsistencies as possible, however, not all problems could be solved for all countries. Finally, the majority of the profiles were transformed to the common reference system. All these profiles were put into an Arc/Info coverage having a point topology and were plotted on a map of Europe using a standard Europe-wide projection system.

The transformed geo-references were plotted for each country on the Digital Chart of the World, which shows the frontiers, the hydraulic network and the main towns, and distributed to the contributors for checking. An overlay with the Soil Geographical Data Base of Europe at scale 1 : 1 000 000 was then made to find the Soil Mapping Units (SMU) in which at least one profile is located. This, in combination with other data from HYPRES such as, FAO soil type, FAO texture class, horizon depths and parent materials can be used as an independent validation of the Soil Geographical Data Base.

Figure 14 shows the location of the profiles in the HYPRES database. Despite the fact that a number of profiles could not be shown, it is clear from Figure 24 that the distribution of the profiles over Europe is not very uniform. It appears that even the participation of as many as 18 institutions does not guarantee that uniformly spaced data are collected. However, the large benefit of depicting the location of the profiles is that in future data collection exercises emphasis can be placed on regions for which these data are lacking presently.

5.3 Estimation of available water on a European scale

Using the class pedotransfer functions, available water capacities were calculated for the different topsoil and subsoil horizons of the Soil Geographical Data Base. In this case, available water was considered to be the water held between field capacity (pressure head = -50 cm) and wilting point (pressure head = -15000 cm). These limits are similar to those set by Thomasson (1995) as a method for estimating profile available water.

Each Soil Typological Units (STU) of the Soil Geographical Data Base of Europe was characterised by its topsoil and subsoil textures. The depth of the topsoil and the depth of the soil was based on the available descriptions of the STU attributes (King et al., 1995). The amount of available water for each texture class was taken from the derived class pedotransfer functions. Next, the total available water in mm for each STU was calculated with the following equation:

$$W_T = \left(W_{top} . T_{top}\right) + \left(W_{sub} . T_{sub}\right)$$

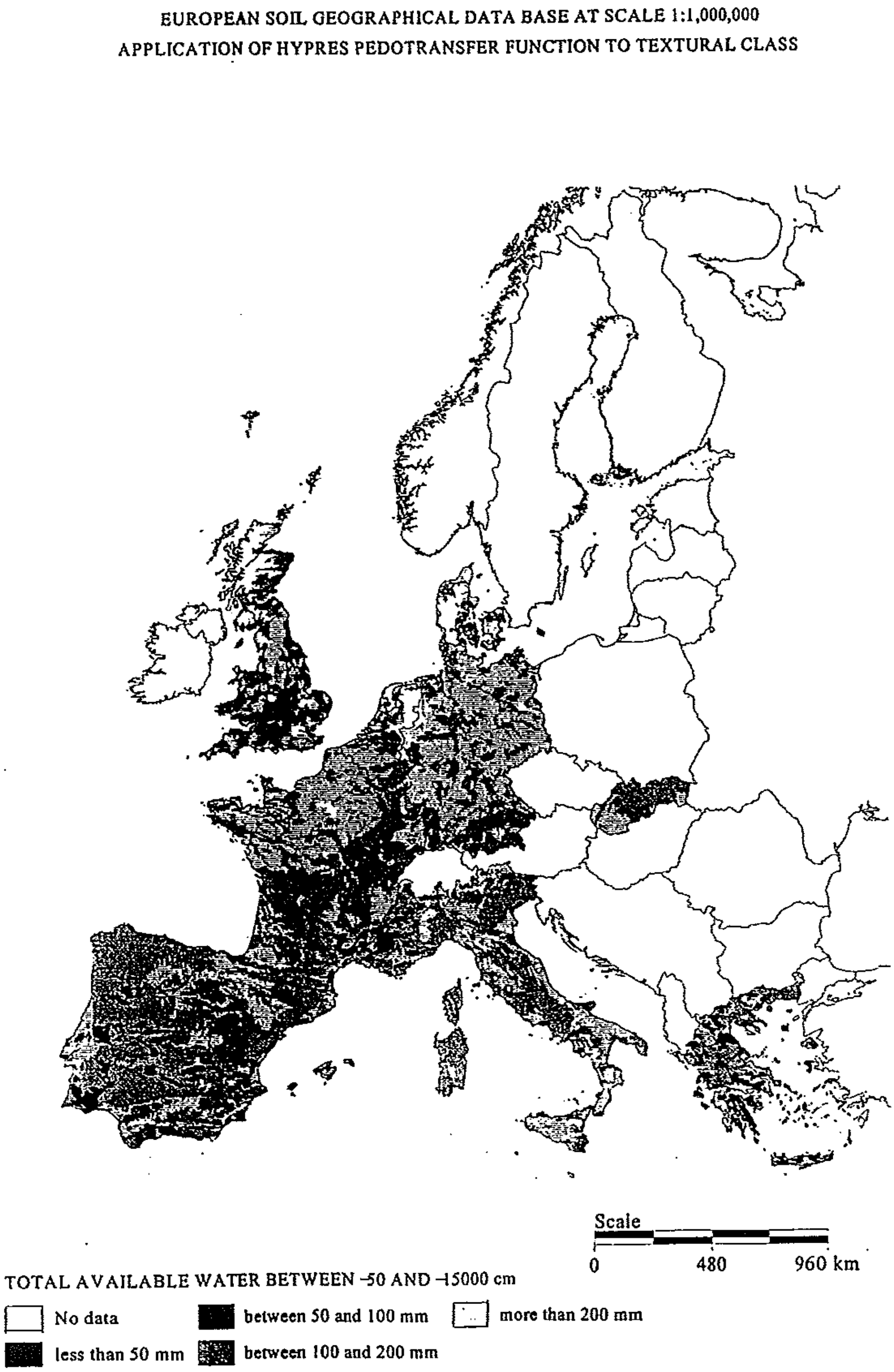


Fig.15 Total available water (mm) between field capacity (h = -50 cm) and wilting point (h = -15 000 cm)

Where:

W_T	=	total available water for the STU
Wtop	=	available water for the topsoil texture class of the STU
Ttop	=	thickness of the topsoil
Wsub	=	available water for the subsoil texture class of the STU
Tsub	=	thickness of the subsoil

Using the estimated values for each STU of the Soil Geographical Data Base of Europe, Figure 15 shows the map of total available water on a European scale. This map is just one example of the type of new information that can be generated when the derived pedotransfer functions are used in combination with other existing European soil data such as the Soil Geographical Data Base of Europe. Future study is required to compare the total available water contents as calculated with pedotransfer functions with those obtained when using pedotransfer rules such as for example Thomasson, 1995.

6 Conclusions and recommendations

Reflecting on what has been learned during this project, a number of conclusions and recommendations can be made.

6.1 Conclusions

1. The HYPRES database constitutes a unique source of information on soil hydraulic characteristics of European soils. Continuing creative and innovative use of this information (e.g. neural networks, other types of correlation, linkage with other European databases) is highly recommended as it might produce unexpected and useful new information.

2. Use of different measurement techniques by the institutions that contributed soil hydraulic characteristics, will contribute to the variability of the individual measured characteristics for a texture class. This 'method-effect' can not be distinguished from the spatial variability effect in a texture class.

3. The number of individually measured characteristics varies greatly for the different texture classes. For example, for very fine textured topsoils the mean characteristic is based on only 21 characteristics. Whereas for medium textured subsoils the mean characteristics is based on as many as 1181 characteristics. These differences in numbers have consequences for how representative the mean characteristics for particular texture classes are.

4. Classification of measurements is based on texture information of the soil horizons on which measurements are carried out. This implies that differences in for instance geological formation and soil structure which all may well lead to a different hydraulic behavior, are not taken into account.

5. By making use of the 11 texture classes of the 1 : 1 000 000 scale Soil Geographical Data Base of Europe, the derived pedotransfer functions can be applied on a national scale of 1 : 1 000 000 or more general. The presented pedotransfer functions are not applicable for more detailed applications. In the latter case it is necessary to measure the hydraulic characteristics of the profile at the particular location.

6. The HYPRES database and its derived pedotransfer functions make it possible to assign soil hydraulic characteristics to soils with a textural composition comparable to the soils for which these pedotransfer functions have been derived. However, the functions should not be used for the assignment of hydraulic characteristics to soils outside Europe. In the first case, an acceptable form of data interpolation is carried out, whereas in the second case a very risky form of data extrapolation is applied.

7. Both class and continuous pedotransfer functions are derived. Class pedotransfer functions give the mean hydraulic characteristics for rather broadly defined soil texture classes. As a consequence, these functions are generally applicable, but they give limited site specific information. In contrast, continuous pedotransfer functions are more site specific as they use site specific information. However, their general applicability is limited.

6.2 Recommendations

1. Collecting measured soil hydraulic information from different institutions across Europe, storing them in one central HYPRES database and deriving pedotransfer functions was a rewarding and useful exercise. It is recommended that the end products of this in-depth investment be used by many researchers working on European agricultural and environmental issues.

2. Working in a network structure during this project proved to be very useful with mutual contacts stimulating the exchange of ideas and methods. This has led to the increasing uniformity in approaches and measurement techniques amongst the partners involved with the consequence of national databases that are also becoming more compatible.

3. It is recommended that soil hydraulic data from countries in Central and Eastern Europe be added to the HYPRES database as they are presently missing. This is of particular importance as these countries already co-operate in the formation of European databases containing other soil data.

4. Linking the results of the HYPRES database with the Soil Geographical Database of Europe at scale 1 : 1 000 000 offers the possibility to generate new information on the European scale such as a water availability map. It is recommended to continue the use of the different European databases in an integrative way and to generate new information useful for scientists, planners and politicians.

5. The European Soil Bureau (ESB) acts as an excellent stimulator as it brings together European soil scientists working in different disciplines. Their functioning stimulated the exchange between different working groups and thereby stimulated the generation of new information.

6. It is recommended that periodic updates of the pedotransfer functions be made when more data become available. The ongoing process of adding new data and updating will result in improvement of the end products and will increase the applicability of the end products for Europe as a whole.

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Appendix 1 Database Structure

Overview of the structure of the European soil hydraulic properties database HYPRES. Each column represents a separate table linked by geo-reference and horizon.

BASICDATA	SOIL_PROPS	HYDRAULIC_PROPS	RAWPSD	RAWRET	RAWK
Gridref	gridref	Gridref	gridref	gridref	gridref
Name	horizon	Horizon	horizon	horizon	horizon
FAO_soil	top_depth	dmvg_sat	psize	flag	flag
Country	bot_depth	dmvg_resid	pcent	head	ind_var
Localngr	structure1	dmvg_alpha		theta	var
Local_soil	structure2	dmvg_n			cond
Localseries	clay	dmvg_m			
Top_depth_gw	silt	dmvg_l			
Bot_depth_gw	sand	dmvg_ks			
Sitedescrip	ksat	theta0			
Sampledate	satwat	theta10			
Annrain	bulk_den	..theta16000			
Ave_jan_temp	particle_den	cond0			
Ave_jul_temp	porosity	cond10			
Contact_name	org_mat	..cond16000			
Contact_address	mvg_sat				
Email	mvg_resid				
Publicn	mvg_alpha				
Comments1	mvg_n				
Comments2	mvg_m				
Keywords	mvg_l				
Number_hor	mvg_ks				
Rating	flag_50				
Rated_by	comments				
	keywords				

Appendix 2 Structure of the individual tables in HYPRES

BASICDATA Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
Gridref	CHAR	16	geo-reference to 1m resolution using European standard system
Name	VARCHAR2	30	profile name to allow reference to a soil profile description
FAO_soil	VARCHAR2	10	FAO soil unit code modified for Europe (CEC, 1985)
Country	CHAR	3	numeric code for each country
Localngr	VARCHAR2	25	geo-reference using a national system eg national grid
Local_soil	VARCHAR2	80	soil type using indigenous classification
Localseries	VARCHAR2	30	soil series name of the soil
Top_depth_gw	CHAR	6	upper boundary of the groundwater table
bot_depth_gw	CHAR	6	lower boundary of the groundwater table
sitedescrip	VARCHAR2	255	description of the sample site
sampledate	DATE		date when the sample was taken
annrain	VARCHAR2	5	long term average annual rainfall of the locality (mm)
ave_jan_temp	VARCHAR2	5	long term average January temperature (degrees Celsius)
ave_jul_temp	VARCHAR2	5	long term average July temperature (degrees Celsius)
contact_name	VARCHAR2	30	a contact to obtain more information
contact_address	VARCHAR2	255	the contact address
email	VARCHAR2	40	email address
publicn	VARCHAR2	255	any relevant publication
comments1	VARCHAR2	255	comments, for example, on methodology, site, reason for sampling, related profiles
comments2	VARCHAR2	255	additional, or a continuation of, comments1
keywords	VARCHAR2	255	keywords to describe the data and methodologies
number_hor	NUMBER	2	number of horizons sampled per profile
rating	NUMBER	2	subjective rating of the quality of the data, generally made by the data owner
rated_by	CHAR	30	name of the person rating the data

SOIL_PROPS Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
gridref	CHAR	16	geo-reference to 1m resolution using European standard system
horizon	CHAR	7	horizon designation (following the FAO guidelines)
top_depth	NUMBER		upper sample depth
bot_depth	NUMBER		lower sample depth
structure1	VARCHAR2	45	primary soil structure (following FAO guidelines)
structure2	VARCHAR2	45	secondary soil structure (following FAO guidelines)
clay	NUMBER		percentage of clay as defined by FAO (<2 μm)
silt	NUMBER		percentage of silt as defined by FAO (2-50 μm)
sand	NUMBER		percentage of sand as defined by FAO (50-2000 μm)
ksat	NUMBER		measured saturated hydraulic conductivity (cm day^{-1})
satwat	NUMBER		measured saturated water content
bulk_den	NUMBER		dry bulk density (g cm^{-3})
particle_den	NUMBER		particle density (g cm^{-3})
porosity	NUMBER		total soil porosity
org_mat	NUMBER		organic matter content (not organic Carbon)
mvg_sat	NUMBER		contributed Mualem-van Genuchten (MVG) parameter of saturated water content
mvg_resid	NUMBER		contributed MVG parameter of residual water content
mvg_alpha	NUMBER		contributed MVG parameter alpha
mvg_n	NUMBER		contributed MVG parameter n
mvg_m	NUMBER		contributed MVG parameter m
mvg_l	NUMBER		contributed MVG parameter *l*
mvg_ks	NUMBER		contributed MVG parameter of saturated hydraulic conductivity
flag_50	VARCHAR2	6	indicates whether the 50 μm particle size fraction was measured or estimated
comments	VARCHAR2	255	comments on methodologies to derive the above values
keywords	VARCHAR2	255	keywords to describe measurement techniques

HYDRAULIC_PROPS Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
Gridref	CHAR	16	geo-reference to 1m resolution using European standard system
Horizon	VARCHAR2	7	horizon designation (following the FAO guidelines)
dmvg_sat	NUMBER		derived Mualem-van Genuchten (MVG) parameter of saturated water content
dmvg_res	NUMBER		derived MVG parameter of residual water content
dmvg_alpha	NUMBER		derived MVG parameter alpha
dmvg_n	NUMBER		derived MVG parameter n
dmvg_m	NUMBER		derived MVG parameter m
dmvg_l	NUMBER		derived MVG parameter *l*
dmvg_ks	NUMBER		derived MVG parameter saturated hydraulic conductivity
theta0	NUMBER		derived saturated water content
theta10	NUMBER		derived water content at -10 cm pressure head
theta20	NUMBER		derived water content at -20 cm pressure head
theta50	NUMBER		derived water content at -50 cm pressure head
theta100	NUMBER		derived water content at -100 cm pressure head
theta200	NUMBER		derived water content at -200 cm pressure head
theta250	NUMBER		derived water content at -250 cm pressure head
theta500	NUMBER		derived water content at -500 cm pressure head
theta1000	NUMBER		derived water content at -1000 cm pressure head
theta2000	NUMBER		derived water content at -2000 cm pressure head
theta5000	NUMBER		derived water content at -5000 cm pressure head
theta10000	NUMBER		derived water content at -10000 cm pressure head
theta15000	NUMBER		derived water content at -15000 cm pressure head
theta16000	NUMBER		derived water content at -16000 cm pressure head
cond0	NUMBER		derived saturated hydraulic conductivity
cond10.......	NUMBER		derived hydraulic conductivity pressure head up to a
cond16000	NUMBER		derived hydraulic conductivity at -16000 cm pressure head with pressure heads as those for derived water contents

RAWPSD Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
gridref	CHAR	16	geo-reference to 1m resolution using European standard system
horizon	CHAR	7	horizon designation (as per FAO guidelines)
psize	NUMBER		upper particle size range (expressed in µm)
pcent	NUMBER		percentage of particles within the specified size range

RAWRET Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
gridref	CHAR	16	geo-reference to 1m resolution using European standard system
horizon	CHAR	7	horizon designation (as per FAO guidelines)
flag	CHAR	1	indicates whether the data are field or laboratory measurements
head	NUMBER		value of the pressure head applied (cm)
theta	NUMBER		moisture retained at the specified pressure head

RAWK Table for HYPRES

FIELD NAME	TYPE	SIZE	COMMENTS/DESCRIPTION
gridref	CHAR	16	geo-reference to 1m resolution using European standard system
horizon	CHAR	7	horizon designation (as per FAO guidelines)
flag	CHAR	1	indicates whether the data are from field or laboratory measurements
ind_var	CHAR	5	indicates whether the conductivity is related to pressure head (cm) or to moisture content (theta)
var	NUMBER		value of the indicator variable in units of pressure head (cm) or theta (proportion)
cond	NUMBER		hydraulic conductivity at the specified value (cm day^{-1})

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Appendix 4 Contents of the HYPRES website http://www.mluri.sari.ac.uk/hypdescr.htm

HYPRES Database:

The EU have funded a project in which a number of European Institutions are collaborating to develop the HYPRES database (HYdraulic PRoperties of European Soils). The distribution of the participating institutions is shown in the accompanying map. The project is co-ordinated by Dr Henk Wösten of the Winand Staring Centre, Wageningen and the project researcher is Dr Allan Lilly of the Macaulay Land Use Research Institute, Aberdeen. The project began in January 1995 and will end in December 1997. During the first two years a database of soil hydraulic properties and relevant soil attributes was compiled (see database structure). This database (HYPRES) has geo-reference and horizon has the unique identifiers of approximately 4900 soil horizons.

Application and Methods:

The primary use of the data within the current project is to derive class pedotransfer functions for topsoils and subsoils based on the five soil texture classes (plus organic soils) currently used to describe the soil units depicted on the 1: 1 000 000 Soil Map of Europe. Initially, the measured soil hydraulic data from each individual soil horizon will be parameterised using the Mualem-van Genuchten equations and grouped according to soil texture class. These equations will then be used to derive mean hydraulic properties for each texture class along with standard deviations (see hydraulic properties). The overall result will be a map showing the soil physical composition of Europe and a set of non-scale-specific pedotransfer functions.

Beyond the lifetime of the project the database will comprise the basic dataset of the European Soil Bureau 'Soil Hydraulic Parameters' working group. The co-workers within this group envisage much wider applications for this dataset within both applied and strategic research.

HYPRES HOMEPAGE | DISTRIBUTION OF PARTNERS | DATABASE STRUCTURE | TEXTURE CLASSES | HYDRAULIC PROPERTIES

MACAULAY LAND USE RESEARCH INSTITUTE

sc-dlo

HYPRES

[HYdraulic PRoperties of European Soils]

The HYPRES database has been developed as an integral part of the EU funded project.

"Using existing soil data to derive hydraulic parameters for simulation modelling in environmental studies and in land use planning".

This Network activity also constitutes a working group of the European Soil Bureau

The project is funded under DG XII, Human Capital and Mobility ~ CHRX-CT94-0639.

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Latest Update

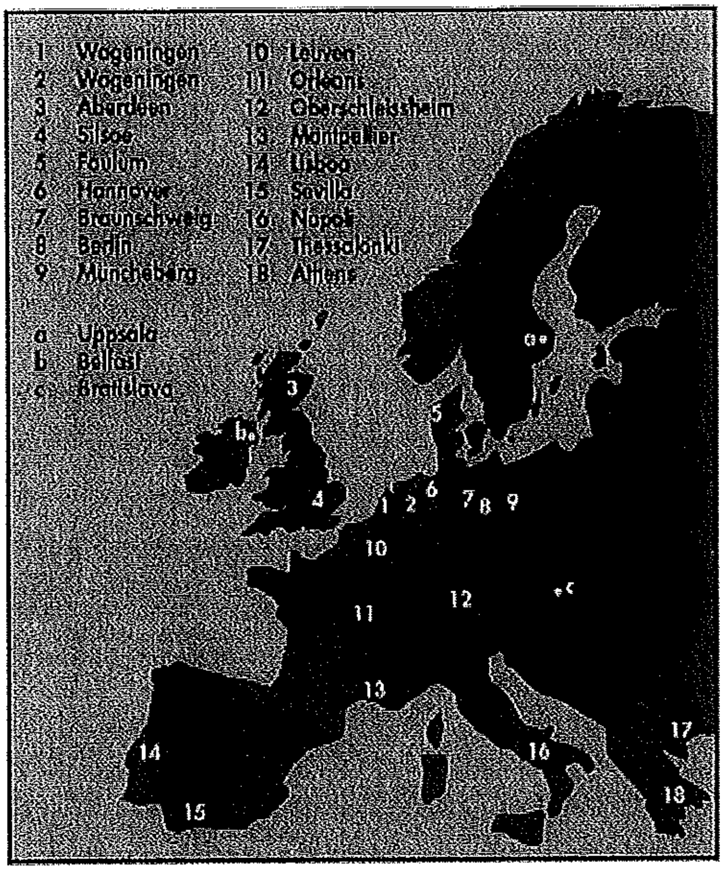
Introduction:

Simulation models are increasingly being used to investigate and predict a wide range of complex environmental processes. Many of these models are concerned with water and solute movement in the vadose zone and require water retention and unsaturated hydraulic conductivity data. However, these properties are difficult and time consuming to measure and there is renewed interest in the establishment of pedotransfer functions in order to estimate them from more easily measured soil properties.

PROJECT DESCRIPTION | DISTRIBUTION OF PARTNERS | DATABASE STRUCTURE | TEXTURE CLASSES | HYDRAULIC PROPERTIES

HYPRES

Distribution of Institutes in the Network



HYPRES HOMEPAGE	PROJECT DESCRIPTION	DATABASE STRUCTURE	TEXTURE CLASSES	HYDRAULIC PROPERTIES

HYPRES

Structure of the HYPRES database.
Each column represents a seperate table linked by georeference and horizon.

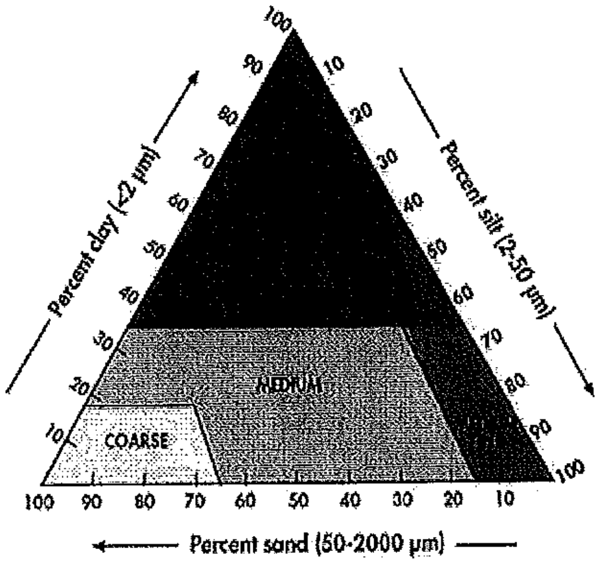
BASICDATA	SOIL_PROPS	RAWPSD	WAT_RET	RAWRET	KUNSAT	RAWUNSA
gridref	gridref	gridref	gridref	gridref	gridref	gridref
name	horizon	horizon	horizon	horizon	horizon	horizon
FAO_soil	top_depth	psize	flag	flag	flag	flag
country	bot_depth	pcent	head1	head	ind_var	ind_var
localngr	structure1		head2	theta	var1	var
localmssg	structure2		...head25		var2	cond
localseries	USclay		theta1		...var25	
top_depth_gw	USsilt		theta2		cond1	
bot_depth_gw	USsand		...theta25		cond2	
sitedescrip	ksat		comments		..cond25	
sampledate	satwat		keywords		comments	
annrain	bulk_den				keywords	
ave_jan_temp	particle_den					
ave_jul_temp	porosity					
contact_name	org_mat					
contact_address	mvg_sat					
email	mvg_resid					
publicn	mvg_alpha					
comments1	mvg_n					
comments2	mvg_m					
keywords	mvg_1					
number_hor	mvg_ks					
rating	comments					
rated_by	keywords					

HYPRES HOMEPAGE | PROJECT DESCRIPTION | DISTRIBUTION OF PARTNERS | TEXTURE CLASSES | HYDRAULIC PROPERTIES

European soil map texture classes

HYPRES

EU Soil Map Texture Triangle

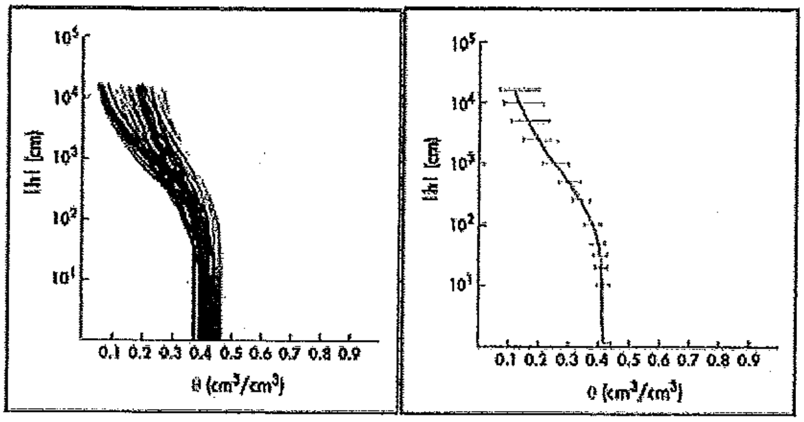


HYPRES HOMEPAGE	PROJECT DESCRIPTION	DISTRIBUTION OF PARTNERS	DATABASE STRUCTURE	HYDRAULIC PROPERTIES

HYPRES

Soil Hydraulic Properties

Water Retention



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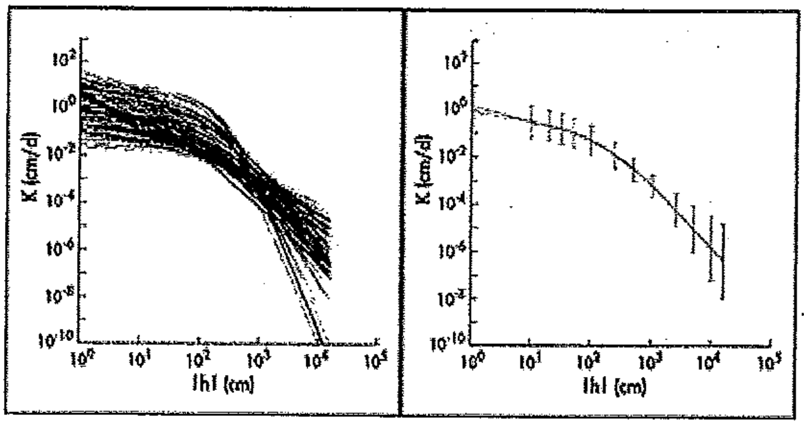

HYPRES HOMEPAGE	PROJECT DESCRIPTION	DISTRIBUTION OF PARTNERS	DATABASE STRUCTURE	TEXTURE CLASSES

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