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ESTIMATION OF THE WATERHOLDING-CAPACITY OF SOILS IN EUROPE
THE COMPILATION OF A SOIL DATASET

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INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

Simulation Reports CABO-TT

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ABSTRACT

As a contribution to an agro-climate study, a simple method was set up to estimate the available water-holding capacity (AWC) of soils in Europe.

Soil data taken from maps were stored on the basis of a 1/2 x 1/2 degree grid. For each grid cell three dominant soil types were recorded, with information on topsoil texture, stoniness and slope. The dataset covers the European territory up to the 44th degree of longitude.

The method for estimating AWC is based on texture-available reserve relations, given in the literature. For five texture classes mean values of available reserve (cm/cm soil) were summarized in a conversion table. The crop rooting depth determines the thickness of the soil layer contributing to the AWC. The rooting depth was derived from the soil type. A reduction factor was proposed for stony soils.

For each grid cell a mean AWC-figure can be determined by taking into account the relative proportions of the soil types concerned. An example was worked out for the cells covering The Netherlands.

1 INTRODUCTION

In 1987 an agro-climate research project was started on behalf of the European Community. The aim is to investigate the effects of possible changes in climate on the agricultural production in Europe. Part of the project deals with validation, comparison and evaluation of several crop-growth simulation models. Each model will be reviewed to produce comparable results for given input data, crop types and agro-climatic regions in Europe.

In addition to climatic data, there was a need for information on the distribution of soil types and relevant soil characteristics in Europe in order to calculate the available water-holding capacity (AWC) of the soil as input in a waterbalance model.

While making an inventory of the available soil information, some problems turned up. Soil data of an appropriate scale are available on various soil maps, showing a variety of legends and classification systems. Furthermore, digitized soil maps could not be used, for only part of the European soil maps are available in digital form.

The idea arose to construct a database to store the soil information for Europe on a small scale. The following requirements were recognized:

- The soil database should unite the information from the available variety of maps and legends.
- It should represent most soil data, necessary for the estimation of AWC.
- The scale at which the soil data are stored should fit the scale of the agro-climate study.
- Handling the database and manipulating the data with a personal computer should be possible, allowing direct and easy use of the results. The data should be presented so as to guarantee accessibility to potential users.

The terminology used in soil science makes soil information often little accessible to workers in other fields. Even for pedologists it can be difficult to use and relate the existing variety of legends and classification systems. Moreover, users of soil data in other disciplines are seldom interested in the soil itself but want information on e.g. possible rooting depth of crops, available water for crop growth, erosion risk, acid neutralizing capacity. There is a need for converting the pedological terminology into directly manageable terms. Efforts must be made to give an impression of the geographical distribution of these variables.

2 PROCEDURE

2.1 Successive steps

The main objective of this project is to make information as shown on soil maps covering Europe suitable for use in a crop-growth model. The following steps were distinguished:

1. Reduction of the soil data to basic entities of soil units with their soil characteristics.
2. Setting up of a database by storing the information on the basis of a 1/2 x 1/2 degree grid.
3. Proposing methods for estimating AWC from the soil units and supplementary characteristics.

It is important to produce flexible data to enable direct use and to guarantee easy incorporation of new ideas and concepts. The data should be compact and allow simple manipulation.

AWC is one of the most frequently used soil parameters. In combination with climatic and environmental information it determines the soil water supply in rainfed agriculture. In this study, AWC of soils in Europe was estimated by use of simple relations between soil characteristics as shown on maps and mean values of available reserve.

2.2 Data handling

selection of the area to be covered

At the beginning of the project it was agreed upon that a soil database should be set up covering all the European territory, although the agro-climate study refers to limited regions only, determined by the climatic data. In this way the database for Europe would be complete, promoting use by others. When it turned out that covering the whole continent would take too much time, the 44th degree of longitude was set as eastern boundary. In this way the dataset includes the greater portion of the European part of the USSR.

selection of soil maps

Soil information was taken from maps present in the map collection of the International Soil Reference and Information Centre. Where available, maps on scale 1:1,000,000 were chosen. The detail of information on this scale is convenient for representing major differences in soil type and characteristics. However, not for all European countries maps on the desired scale are available. For some nations maps on scale 1:2,000,000 were present, while for others use had to be made of the 1:5,000,000 FAO-Unesco Soil Map of the World. As a result not all stored data refer to the same detail of information. A review of maps used is given in Appendix A.

selection of grid size

The data were stored on the basis of a 1/2 x 1/2 degree grid. The soil maps were overlain by a lattice and from each grid cell the principal information was taken. The extent of the territory represented by the grid cells varies with latitude. In lat.50 a grid cell refers to approximately (55x35) km^2.

The chosen grid size is appropriate when maps on scale 1:1,000,000 are used. The information can be stored without losing too much detail. On the other hand the number of grid cells is not too large to handle. The European territory under consideration comprises approximately 4,500 grid cells.

It must be realized that part of the geographical information is lost. The %-distribution of three major soil units in a grid cell is stored, but their distribution pattern can not be reproduced using a 1/2 x 1/2 degree lattice.

reduction of soil information

For each grid cell the three dominant soil types were selected and their relative proportions determined. As most mapping units consist of soil associations, first all major soil types with associated types were dissected and compared. They were regrouped to form three soil types, considering the principal differentiating soil properties and soil forming processes. E.g. shallow soils containing little organic matter were combined with shallow soils containing an organic-rich layer to separate them from deep soil profiles.

selection of soil units and characteristics presented

The mapping units on maps of scale 1:1,000,000 often not only contain the soil type, but also information on the particle size distribution (soil texture) and the dominant slope. Surface stoniness, depth of a shallow hard rock contact and saline/sodic properties sometimes are designated as phases. Part of this supplementory information was stored in the database, because of their relative importance in calculating AWC. Thus, the following information for each of the three distinguished soil types per grid cell was extracted: topsoil texture, slope, surface stoniness and presence of a shallow lithic contact. Because both soil type and additional information are not indicated on all soil maps, sometimes the data came from different maps, accounted for in Appendix A.

The different classification systems used on the various maps were transcribed into a current classification: the revised legend of the FAO-Unesco Soil Map of the World (FAO 1988). Although not a classification system, the FAO legend serves well to describe soil types and uniform different classification systems. Anticipating on amendments on the current version, a previsional edition of the revised legend was used.

3 DESCRIPTION OF SOILS IN EUROPE (with emphasis on AWC)

Soil types were stored using the terminology of the revised legend of the Soil Map of the World (FAO 1988). This terminology will be briefly reviewed, with emphasis on diagnostic horizons and properties that are important in the calculation of AWC.

Soil classification in general is based on the evidence of soil-forming processes expressed by various features. In the legend of the Soil Map of the World a distinction is made between diagnostic horizons and diagnostic properties. Diagnostic horizons are soil layers with pronounced features. Diagnostic properties are features not related to distinct layers. They are described in terms of soil colour, soil texture, soil depth, organic matter content, cation exchange capacity, soil structure, calcium-carbonate content, salt content, etc. The naming of soils according to the legend of the Soil Map of the World is based on a hierarchy between diagnostic horizons and properties.

Not all features are equally important for indicating soil qualities, such as possible rooting depth of crops, water and oxygen availibility for crop growth, suitablity for mechanical tillage. In this report the discussion on soil names is focussed on soil characteristics related to the estimation of AWC-figures.

The revised legend of the Soil Map of the World is composed of 149 soil units clustered in 28 major soil groupings. In Europe representatives of 23 soil groups occur. The essence of the names of these soil groups is given in this chapter. In addition, the names of some relevant soil units will be described. The distribution of primary soil groups in Europe will also be given.

The names of soil groups and units are discussed on the basis of the following soil characteristics, determining the calculation of AWC: soil texture, alteration of soil layers with marked textural differences, soil structure, soil depth, organic matter content and hydrological condition. The relative importance of these characteristics will be discussed in chapter 5. As far as major soil groups are not distinguished on the basis of one of these characteristics, they will be mentioned later. In the following review major soil groups are underlined.

texture

The particle size distribution is usually not applied as a classification criterion, because it is related to more than one principal soil-forming process. On many maps soil texture is indicated by a separate symbol added to each mapping unit (soil unit or soil association). Arenosols and Vertisols however, are distinguished on the basis of texture.

Arenosols are coarse sandy soils without evidence of any principal soil formation. They are not extensive in Europe. Vertisols are extremely heavy clay soils. They occur in small areas, particularly in southern Spain, Yugoslavia, Bulgaria and Rumania. The vertic soil units (Vertic Cambisols, Vertic Luvisols) are also fine textured, but do not show all characteristic features.

(abrupt) textural change

Layered soil profiles with regard to the particle size distribution can be the result of soil formation or of geological stratification. In case of Luvisols, Acrisols, Solonetz, Planosols and Podzoluvisols, soil formation is responsible for textural changes in the soil profile.

Luvisols and Acrisols have a distinct clay-illuviation layer formed by translocation of clay particles. These two soil groups are separated on the basis of differences in cation exchange capacity. Particularly Luvisols are extensive in Europe. It is the dominant soil group in Greece, Bulgaria and in the north-west of France and occurs in a wide belt north of the Alps and in the USSR. Solonetz are soils with a sodium-rich clay-illuviation layer. In Europe Solonetz are found mainly in small areas in Rumania, Yugoslavia and the USSR. Planosols are soils that combine a clay-eluviation layer with severe water stagnation on the substratum. They occur in a number of European countries, but are restricted to small areas. Podzoluvisols have a clay-illuviation layer with evidence of translocated iron. They are present in a very wide belt between app. Lat.55 and Lat.60 in the USSR.

Geological stratification - the result of sedimentation - is one of the diagnostic criteria for Fluvisols. Fluvisols can be found along rivers and on coastal plains. The sedimentation usually has resulted in relatively thin layers, not very important in the determination of AWC.

structure

Soil structure refers to the arrangement of the solid phase of the soil and the pore space. This characteristic is used to define Regosols. Regosols are soils from unconsolidated materials, with exception of coarse sandy soils (Arenosols by definition). In Europe Regosols are abundant in the Tundra regions and on Sicily, but also occur in small areas in nearly all countries.

soil depth

Shallow soils limited in depth by hard rock or cemented layers within 30cm of the surface are refered to as Leptosols. (Lithic Leptosols are only 10cm thick.) In Europe they are particularly found in the mountainous regions.

organic matter

Peat soils refered to as Histosols largely consist of organic materials. Soils with a high organic matter content in a thick topsoil layer, exclusive of Histosols, are either Kastanozems, Chernozems, Phaeozems or Greyzems. The criteria that divide these four soil groups are not important in the context of this report. Soil units classified in other major soil groups may have a topsoil layer rich in organic matter too. They are refered to as Mollic or Umbric soil units (Mollic-/Umbric Fluvisols, Mollic-/Umbric Gleysols, Umbric Regosols, Mollic-/Umbric Leptosols, Mollic-/Umbric Andosols, Mollic Solonetz, Mollic Solonchaks, Mollic-/Umbric Planosols). Rendzic Leptosols, Humic Cambisols and Fimic Anthrosols complete the compilation of soils rich in organic matter in the topsoil.

Histosols are found in wet places all over Europe, but are very extensive in Finland and in the USSR. Chernozems and Kastanozems are present particularly in Rumania and in the USSR, in a wide belt between Lat.45 and Lat.55, whereas Phaeozems occupy the Hungarian basin.

hydrological condition

Soils with clear evidence of waterlogging for some period of the year are classified as Gleysols, or as Gleyic or Stagnic soil units. Almost all major soil groups contain a Gleyic and/or a Stagnic soil unit. Besides Gleysols, Histosols and Planosols are temporarily waterlogged.

Gleysols are found at places with a high groundwater table (e.g. along rivers), and cover extended areas in the UK, Ireland and the Baltic region.

Seven major soil groups that do occur in Europe are not mentioned in the previous review. They are not classified according to criteria directly related to the determination of AWC.

Andosols are soils developed in volcanic materials and are among others characterised by a low bulk density. Cambisols are soils without clear soil layer development. They are very extensive in Middle Europe, Spain, Italy, Yugoslavia and Rumania. Calcisols, Gypsisols and Solonchaks are characterised by accumulation of calcium carbonate, gypsum and soluble salt respectively. They only occur at some minor locations in southern Europe. Podzols show the evidence of leaching of organic matter and/or iron in the soil profile. They are dominant in Scandinavia, Poland, the nothern part of the USSR and in the north of western Europe. Anthrosols are soils in which human activity, like addition of organic matter over a long period, has strongly influenced the soil formation. Anthrosols occupy only very small areas.

Table 3.1 gives a summary of major soil groups and relevant prefixes of soil units described previously. Figure 3.1 presents a simplified soil map of Europe.

Table 3.1 Major soil groups in Europe with classification criteria related to the determination of AWC.

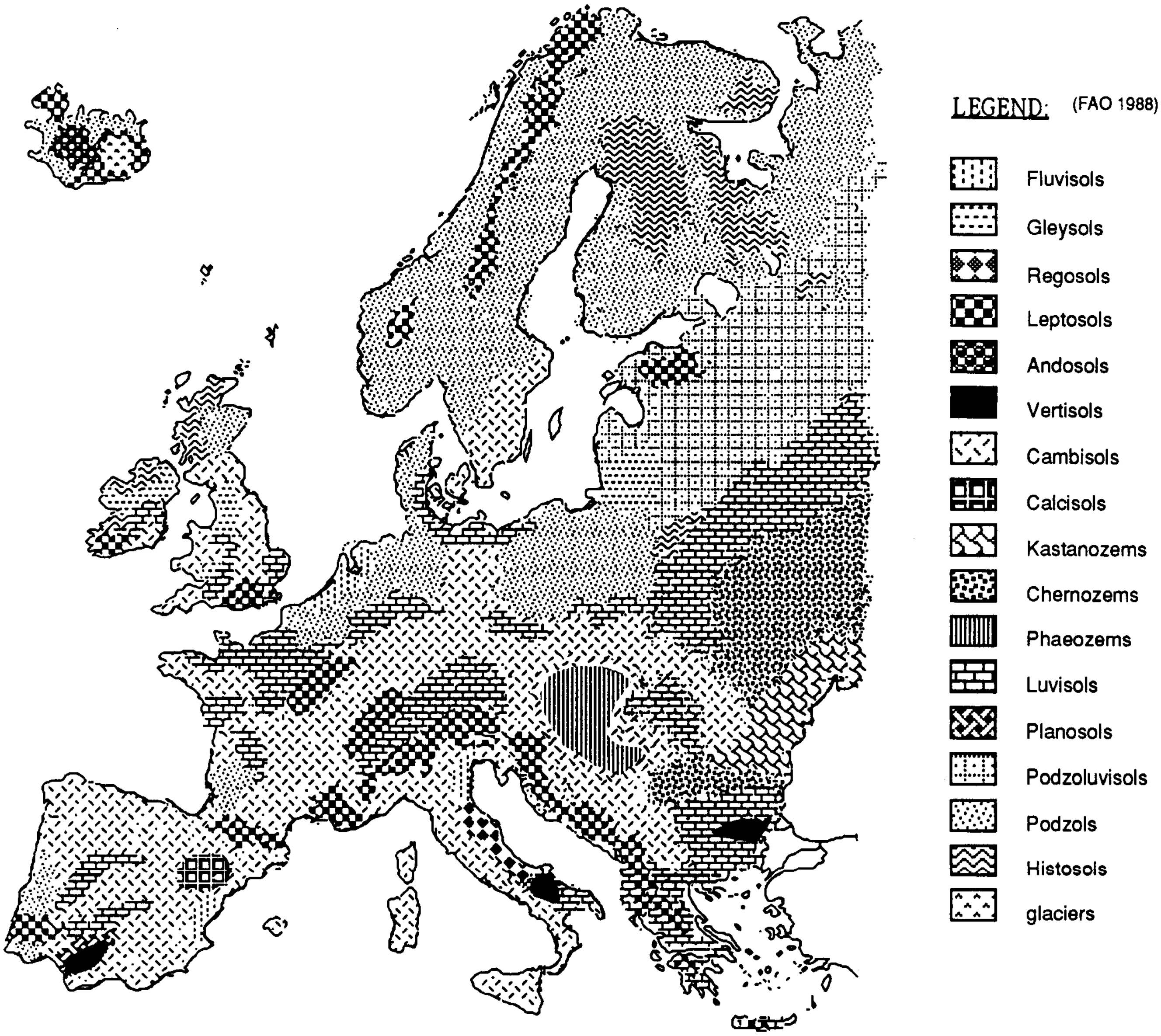
	text.	text.change	struct.	depth	o.m.content	hydr.cond.	surface # (1000 km2)
Fluvisols		(*)					400
Gleysols						*	200
Regosols			*				200
Leptosols				*			900
Arenosols	*						50
Andosols							40
Vertisols	*						40
Cambisols							1600
Calcisols } Gypsisols }							100
Solonetz		*					80
Solonchaks							10
Kastanozems					*		400
Phaeozems					*		1000
Chernozems					*		100
Greyzems					*		60
Luvisols		*					1200
Planosols		*				*	20
Podzoluvisols		*					1600
Podzols							2000
Acrisols		*					<10
Histosols					*		300
Anthrosols							<10
Mollic/Umbric-					*		
Gleyic/Stagnic-						*	
Rendzic Leptosols					*		
Humic Cambisols					*		
Fimic Anthrosols					*		

* = classification criterion is dominant

(*) = classification criterion is of secondary importance

\# = refers to the complete European territory

Figure 3.1 Soil map of Europe



4 DATABASE

4.1 Structure of the database

The data were stored with the help of a spreadsheetprogram. Each record of the spreadsheet contains the information of an entire grid cell (1/2 x 1/2 degree on the map). All records are made up by 18 fields:

- Field 1 = Latitude
- Field 2 = Longitude
- Field 3 = location/country (code)
- Field 4 up to 9 = information on soil type 1, representing:
  - Field 4 = soil type 1 (code)
  - Field 5 = proportion (%)
  - Field 6 = texture top 30cm. (code)
  - Field 7 = slope (code)
  - Field 8 = stony and/or lithic phase (code)
- Field 9 up to 14 = soil type 2 and related information
- Field 14 up to and including 18 = soil type 3 and related information

The arrangement of the data is illustrated in table 4.1

Table 4.1 Example of data arrangement in the soil database (data are coded)

lat.	long.	nation	soil1	%1	text.1	slope1	stone1	soil2	%2	text.2	slope2	stone2	soil3	%3	text.3	slope3	stone3
49.5	5.5	9	74	50	13	2	0	71	30	7	3	3	77	20	13	3	0
49.5	6	9	79	50	13	3	0	71	40	7	3	3	51	10	4	1	0
49	-4.5	0	171	60	9	2	0	178	20	9	2	0	72	20	9	3	0
49	-4	0	171	40	9	2	0	72	40	9	2	0	178	20	9	2	0
49	-3.5	9	171	50	9	2	0	72	30	9	3	0	178	20	9	2	0
49	-3	0	171	80	9	2	0	178	10	9	2	0	0	10	0	0	0
49	-2.5	0	170	60	9	2	0	70	40	10	3	2	0	0	0	0	0
49	-2	0	71	40	9	1	2	170	30	9	1	2	51	30	4	1	0
49	-1.5	9	72	50	9	2	0	171	30	9	2	0	178	20	9	2	0
49	-1	9	170	40	13	3	2	71	40	13	3	2	72	20	9	2	0
49	-0.5	9	71	50	13	3	2	170	30	3	2	2	74	20	13	3	0
49	0	9	70	60	13	3	0	90	20	9	1	2	178	20	13	3	0
49	0.5	9	90	60	9	1	2	178	30	9	1	2	171	10	9	1	2
49	1	9	171	60	9	2	1	71	30	13	3	2	90	10	9	1	2
49	1.5	9	171	34	7	2	0	178	33	9	2	0	90	33	9	1	2
49	2	9	178	50	9	2	0	171	50	9	2	0	0	0	0	0	0
49	2.5	9	171	60	9	2	0	90	30	9	1	0	51	10	4	1	0
49	3	9	90	40	9	1	2	178	30	9	1	0	23	30	7	2	3
49	3.5	9	23	40	7	2	3	90	40	9	1	2	52	20	4	1	0
49	4	9	23	70	7	2	3	74	20	7	2	3	52	10	4	1	0

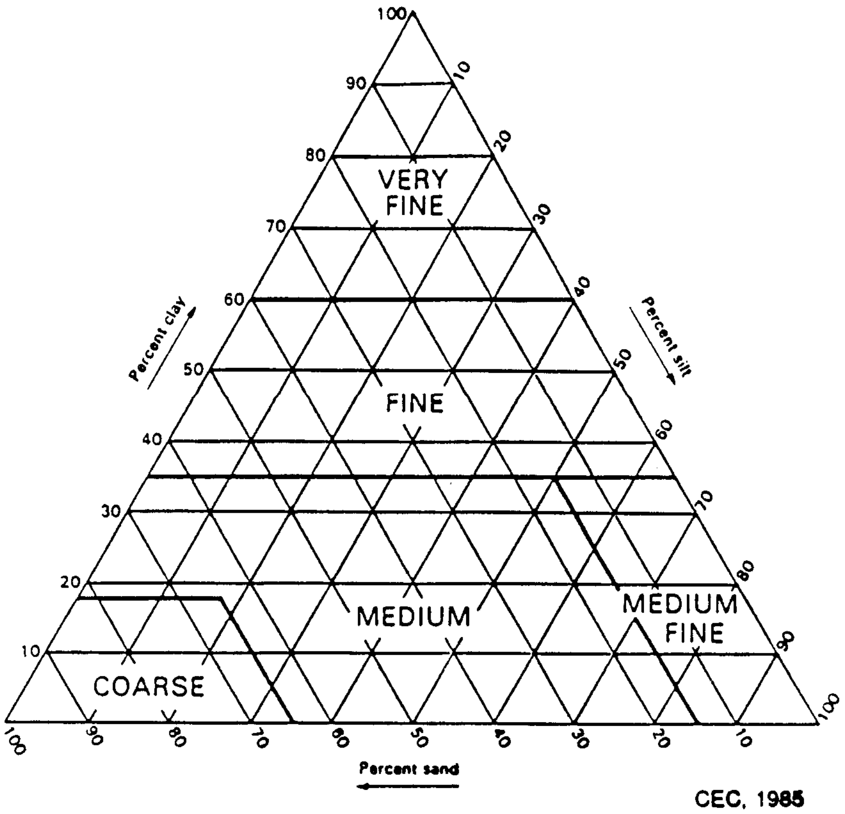
The grid cell co-ordinates (fields 1 and 2) were directly stored in the database. The co-ordinates refer to the left top of each cell. In addition a code with respect to the nation (field 3) was given to complete the geographical information (location codes: Appendix B1). If a grid cell covers the territory belonging to more than one nation, the given code refers to the nation occupying the greater part of the cell. In case the majority of the area concerned is sea/ocean, the location code is 0. If less than 25% of the area covered by a grid cell is land, the cell was not stored.

Soil types (fields 4, 9 and 15) were coded according to Appendix B2. If necessary, related soil units were grouped by using the code of the major soil group.

Fixed ratios (Appendix B3) were used to store the relative proportions of the three dominant soil types in each grid cell (fields 5, 10 and 15).

For the additional information (topsoil texture, slope and stony/lithic phase) classes were defined (Appendix B4, B5 and B6). Fields 6, 11 and 16 refer to the topsoil texture of each soil type. The division in classes was adopted from the Soil Map of the EC (CEC, 1985). The texture triangle used (Figure 4.1) is based on the relative proportions of clay, silt and sand particles in the soil material. Fields 7, 12 and 17 and fields 8, 13 and 18 refer to the slope class and the stony/lithic phase respectively, given for each soil type.

Figure 4.1 Texture triangle



4.2 How to use the database

The database gives a representation of the information shown on soil maps. An advantage of using digital data is their flexibility. It enables repetitive selection and manipulation of the information. A disadvantage of the resolution used is that part of the information is lost. By storing data on a relatively coarse grid part of the geographical distribution is not reproduced. In this exercise from the contents of each 1/2 x 1/2 degree rectangle on the map only three soil types were stored with some additional information. Obviously the result is a considerable reduction of the original information. E.g. from an average grid cell on a map scaled 1:1,000,000 , covering some five soil associations, only three soil types are selected, while soil boundaries are lost. However, for the purpose of this study the relative proportion of principal soil phenomena in an extensive area is more important than their precise location. Thus, a great advantage is the capability of manipulating all stored information separately.

selection of records

For all fields selection criteria can be defined. In this way all records for a specific nation or an area can be isolated and subsequently be changed.

For example, an overview of soil types in a defined area can be obtained by selecting records on the basis of co-ordinates. Subsequently all present soil types with their corresponding relative proportions are selected. These proportions refer to the grid cells, so all proportions must be divided by the number of grid cells under consideration.

When looking at relatively large areas it must be considered that grid cells vary in area reflected, depending on the latitude. In fact the cosine of the latitude equals the relative proportion of the area covered by grid cells. Using this relation a correction can be made. It should be noticed that this correction factor is of greater importance in northern regions and only then relevant - regarding the accuracy of information in each cell - when the area considered extends over more than say ten degrees of latitude.

derivation of soil qualities from the data stored

To determine soil qualities with the help of the database under consideration first the information present and the information needed must be compared. The database contains both directly accessible soil characteristics (topsoil texture, slope, stoniness, presence of a shallow lithic contact) and information enclosed in the soil name. If the characteristics required are present, a simple step by step procedure should lead to estimation of the soil quality concerned.

The estimation of AWC is based on a relation between soil texture and soil water content. Another principal soil characteristic is the possible rooting depth. Supposing that only the topsoil (top 30 cm) contributes to AWC, information on soil texture can directly be taken from the texture figures stored in the database (fields 6, 11 and 16), while the soil depth can be derived from the soil name. When only topsoil texture and rooting depth are taken into account, calculation of AWC is simple. All texture-class figures are replaced by a figure indicating the available reserve in cm/cm soil. Subsequently, the available reserve is multiplied by the rooting depth in cm. All soil types have a possible rooting depth of at least 30cm, except for Lithic Leptosols, which are limited in depth within 10cm of the surface. Considering the relative proportion of each soil type in a grid cell, the estimated AWC for each grid cell can be determined.

5 CALCULATION OF THE AVAILABLE WATER-HOLDING CAPACITY

An estimation of AWC for the European territory derived from soil maps can only be a coarse one. Considering that the AWC-estimates are part of a variety of input data for a small scale crop-growth simulation model, the calculation method suggested is acceptable. The calculation is based on the assumption that soil properties shown on maps can give a reliable estimation of AWC, while soil map units are assumed to be homogeneous with respect to these properties. In reality however, there is a great spatial variability within mapping units.

5.1 Factors determining AWC

The concept of AWC refers to the amount of soil water that is available to plants. The AWC is determined as the difference between moisture content values, corresponding to crop-growth related soil water tensions. Usually an upper limit, the field capacity, and a lower limit, the permanent wilting point, are defined as soil constants. Field capacity refers to the maximum water quantity that can be held by the soil, determined after 48 hours of drainage following rainfall. The permanent wilting point refers to the quantity of water that is inaccessible to plants, because the soil water tension is too high. It is generally accepted that the water content at permanent wilting point equals the water content at pF 4.2. The amount of water at field capacity however, is determined at different pF-values, of which pF 1.7, pF 2.0 and pF 2.3 are most common.

Water available to plants is futhermore determined by the rooting depth and by water supply from the subsoil.

Soil composition and poresize distribution are the principal determinants of soil water retention. Commonly more quantifiable factors related to these determinants are used: soil texture, organic matter content and bulk density. Various studies (e.g. Hall et al 1977, Gupta et al 1979) deal with establishment of the effect of these factors on available water by means of regression analysis. It turns out that for the topsoil the available water content is primarily related to bulk density and organic matter content. In the subsoil the availability of water is determined by soil texture and bulk density. Bulk density however, has a high spatial variability even when focussing on a single field. On a reconnaisance scale an estimation of AWC can be made on the basis of soil texture and organic matter content only (e.g. Madsen et al 1983). Other conversion tables are proposed which directly relate textural classes to AWC-figures. Obviously these mean figures are not meant to refer to the farm level.

Availability of water to plants depends on density and penetration depth of the rooting system. By making use of the effective rooting depth (ERD), defined as the thickness of the soil layer in which the total AWC is utilized by the crop (Madsen et al 1983), the rooting system can be considered as homogeneous. Although showing a high variability, rooting depth is generally related to the presence of soil layers. The soil type gives information on the appearance of rooting barriers. Moreover the presence of a shallow lithic contact usually is indicated on maps as a phase.

Capillary rise of water from the subsoil into the root zone can supply a considerable amount of water to the crop. From the data needed to calculate the capillary rise, the depth to the groundwater table is most important. Unfortunately groundwater figures are not indicated on the maps used.

Neglecting capillary rise however, causes a serious underestimation of AWC in extended areas in Europe.

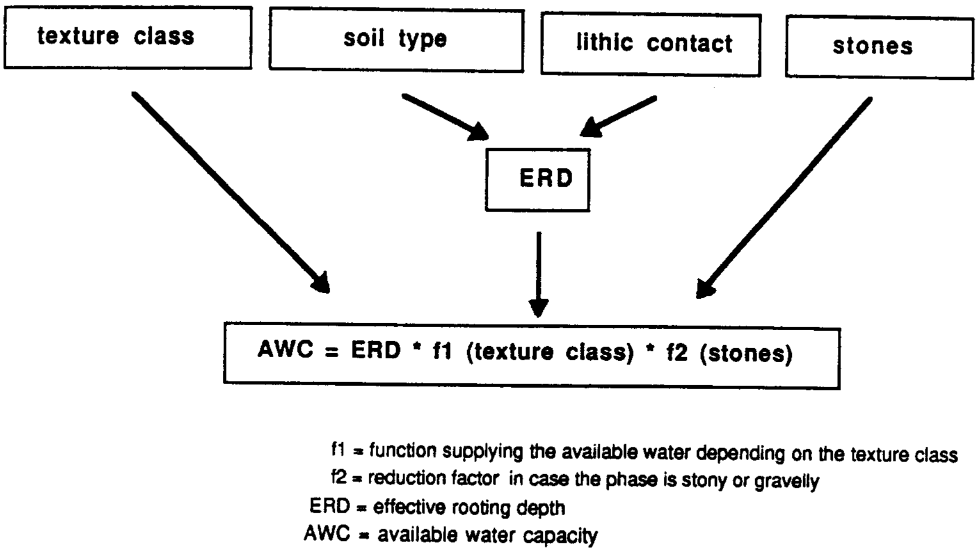
5.2 Suggestions for estimating AWC

In this study AWC is regarded as a static variable: the potential amount of available water stored in the soil profile at the beginning of the growing season. The AWC is determined by soil texture and the effective rooting depth (ERD). A correction factor is introduced for stones and gravels in the soil profile. Capillary rise of groundwater is not taken into account. The calculation procedure is based on a study to estimate the available reserve on the basis of the EC soil map by King et al (1988).

calculation diagram

Figure 5.1 presents a procedure to estimate AWC for each soil type. A mean AWC-figure for each grid cell can be determined by taking into account the relative proportions of the soil types present in a cell.

Figure 5.1 Calculation of AWC



Because of lack of subsoil information, topsoil texture is related to the overall soil profile.

relation between texture and available water

Direct relations between texture classes and available water have been worked out for a variety of national systems of texture classification (e.g. Jamagne et al 1977 for France, Hall et al 1977 for the UK, Rawls et al 1982 for the USA). It is difficult to compare the texture classes because they differ considerably. King et al (1988) determined mean values of available water for the five texture classes used in this study by rearranging the original divisions. For Dutch soils comparable figures can be deduced from the 'Staring reeks' (Wösten et al 1987). The results are reproduced in Table 5.1.

Table 5.1 Mean values of available reserve (cm/cm soil)

texture	USA (1)	Fr (1)	UK sub (1)	UK top (1)	NL (2)
coarse	0.070	0.080	0.120	0.110	0.110
medium	0.140	0.150	0.170	0.210	0.235
med.fine	0.180	0.185	0.190	0.240	0.285
fine	0.120	0.175	0.140	0.200	0.265
very fine	0.125	0.170	0.140	0.190	0.220

(1) = King et al (1988)
(2) = Wösten et al (1987)

The Dutch figures refer to specific soil profiles that fit in the EC texture classes, but can not be considered as representatives for these classes. Furthermore it should be realized that all figures are determined for local soils.

The differences in mean values of available reserve however, are primarily the result of the fact that the various authors use different pF values corresponding to field capacity. For the American, Dutch and English values the soil water content at field capacity is determined at pF 2.5, 2.0 and 1.7 respectively. The French figures are calculated for three different pF values at field capacity, depending on soil texture. The amount of soil water stored decreases considerably from pF 1.7 to pF 2.5, reflected by the mean values of available reserve in Table 5.1. In the light of this study however, they give a convenient and useful overview of texture-available reserve relations.

effective rooting depth

The ERD depends on the crop considered and on the rooting obstructions in the soil profile. For cereals a maximum ERD of 100cm seems reasonable (from figures of Madsen et al 1983). As obstacles in the soil profile impenetrable hard layers, very coarse soil materials, relatively compact soil horizons and water saturated soil layers are distinguished.

Depth to hard rock is indicated on soil maps as a lithic phase or can be derived from the soil type (Leptosols).

It is plausible that coarse soil materials, as in Arenosols, reduce the ERD to 45cm (Madsen et al 1983).

Planosols, Luvisols, Podzoluvisols, Solonetz and Acrisols by definition have a texture change in the soil profile. Only for Planosols this results in a compact soil layer severely hampering root penetration. The depth however at which the compact layer might occur varies. It is proposed to reduce the ERD for Planosols to 55cm, based on a mean depth of 40cm at which the compact layer appears, assuming a root density of this layer of 25%.

Excess of water may limit the rooting depth. It is suggested to reduce the ERD for Gleysols by 30%. In extreme situations, such as in the case of undrained Histosols, cereals will suffer severely from oxygen deficiency. Consequently for Histosols the ERD is 0 because the root system can not develop.

Table 5.2 presents an overview of ERD-values for cereals. Rooting depths vary considerably over short distances and are difficult to establish. Therefore a rough division has been made, based on diagnostic horizons and properties of the soil units.

Table 5.2 ERD for cereals depending on soil characteristics

soil type/phase	ERD (cm)
soil type = Histosols	0
soil type = Lithic Leptosol	10
soil type = other Leptosols	30
presence of a lithic phase	50
soil type = Arenosols,	45
" = Planosols	55
" = Gleysols	70
other soil types	100

ERD = effective rooting depth

stoniness

A substantial amount of stones in the soil profile results in a reduction of soil porosity. Moreover, the root development can seriously be hampered by stones. It is suggested to reduce the available water reserve by 30% when the phase is stony or gravelly (King et al 1988).

example

The AWC was calculated for the grid cells belonging to the Dutch territory in five steps, following Figure 5.1.

1 Grid cells with location code 17 were set apart, resulting in 17 cells.

2 For these grid cells new fields were created for the texture-available reserve function (fields AR1, AR2 and AR3 for the three soil types respectively). The available reserve figures were taken from Wösten et al (1987), resulting in the following conversions:

If texture code = 1	then available reserve = 0.110 cm/cm soil
If texture code = 2,3,4,5,6,11	then available reserve = 0.235 ,,
If texture code = 7,9,10,12	then available reserve = 0.285 ,,
If texture code = 8,13,14	then available reserve = 0.265 ,,
If texture code = 15	then available reserve = 0.220 ,,
If texture code = 0	then available reserve = 0.450 ,,

Thus the fifteen texture classes were regrouped to fit the conversion table. When no texture code is present (soil unit is absent or Histosol) the available reserve figure is 0.450 cm/cm soil, representing peat soils (from figures of Wösten et al 1988).

3 New fields were created for the determination of ERD (fields ERD1, ERD2 and ERD3 for the three soil types respectively). The ERD depends on the soil type, according to Table 5.2.

4 Three new fields were created for a reduction factor in case of a stony/lithic phase. If stones or gravels are present (code = 1 or 2), the reduction factor is 0.70. In case of a lithic contact (code = 3,4 or 5), the reduction factor is 0.50. Otherwise the factor is 1.00.

Table 5.3 gives the result of the foregoing steps for the first soil type in all grid cells.

Table 5.3 Result of the first step in the calculation of AWC for the first soil type in the 17 grid cells representing the Dutch territory.

soil type	%	texture	phase	AR (cm)	ERD (cm)	reduction
51	50	13	0	0.265	100	1
100	40	1	0	0.110	100	1
50	50	8	0	0.265	100	1
50	50	4	0	0.235	100	1
52	60	8	0	0.265	100	1
105	60	1	0	0.110	100	1
105	70	1	0	0.110	100	1
10	40	0	0	0.450	0	1
52	50	8	0	0.265	100	1
104	40	1	0	0.110	100	1
105	60	1	0	0.110	100	1
105	60	1	0	0.110	100	1
52	70	8	0	0.265	100	1
50	60	8	0	0.265	100	1
51	40	13	0	0.265	100	1
105	34	1	0	0.110	100	1
100	60	1	0	0.110	100	1

phase = stoniness/lithic contact
AR = available reserve
ERD = effective rooting depth
reduction = reduction factor in case of stones, gravels or a shallow lithic contact
AWC = available water capacity

5 Subsequently the AWC for grid cells was determined by multiplying the results for each soil type with their relative proportion:
AWC = %1(AW1 * ERD1 * reduction1) + %2(AW2 * ERD2 * reduction2) + %3(AW3 * ERD3 * reduction3)

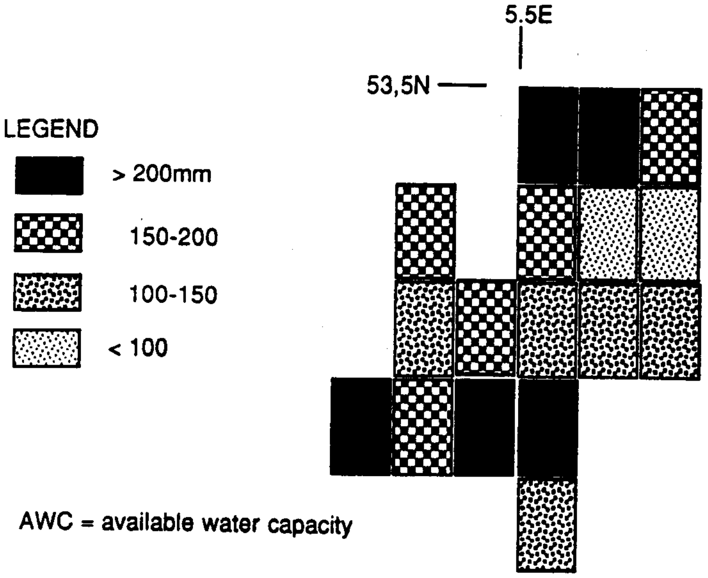
The results are given in Table 5.4 and Figure 5.2.

Table 5.4 Results of AWC-calculation for the grid cells representing the Dutch territory.

latitude	longitude	AWC (mm)
53.5	5.5	239
53.5	6	203
53.5	6.5	166
53	4.5	173
53	5.5	170
53	6	81
53	6.5	85
52,5	4.5	126
52.5	5	166
52.5	5.5	147
52.5	6	103
52.5	6.5	103
52	4	250
52	4.5	181
52	5	210
52	5.5	202
51.5	5.5	138

AWC = available water capacity

Figure 5.3 AWC-classes for all grid cells covering the Dutch territory.



slope

To conclude with, slope class is briefly discussed. This factor does not reduce the AWC but strongly influences the utilization of the total storage capacity in soils and in this way the effective use of AWC by plants.

On slopes run off of water is to be expected. On extreme slopes soil depth usually is restricted, limiting the influence of run off on utilization of the storage capacity. On moderate slopes however, many factors are involved. Perhaps this factor could be taken into account, while establishing a waterbalance.

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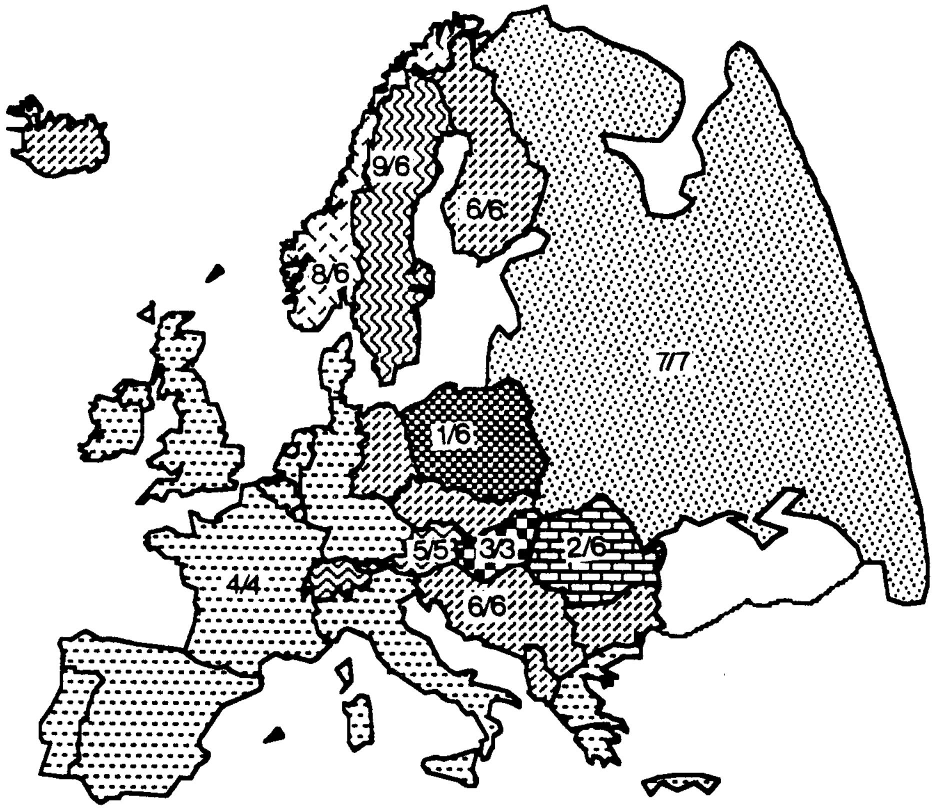
APPENDICES

Appendix A: soil maps used

1- Mapa gleb Polski wedlug nomenklatury FAO, 1:2,000,000; 1984
2- Harta solurilor republich socialiste Romania, 1:1,000,000 - "Institul de Geologie si Geofizica; 1978
3- Soil map of Hungary 2nd draft, 1:1,000,000; 1973
4- Soil map of the European Communities, 1:1,000,000 - "Commision of the European Communities"; 1985
5- Soil map of Middle Europe, 1:1,000,000 - "International Society of Soil Science"; 1985?
6- Soil map of the world; Volume V, Europe, 1:5,000,000 - "FAO - Unesco"; 1981
7- Soil map of the European part of the USSR, 1:1,000,000 - "USDA" ; compiled 1965, revised 1975
8- Nasjonalatlas for Norge; Jordbunnskart (Soil map of Norway), 1:1,000,000 "Norges geografiske oppmaling"; 1983
9- Sweriges Jordmaner/Soil map of Sweden, 1:1,000,000 - "Swedish University of agricultural sciences"; 1986



For the hatched area soil types are taken from map 8 / additional information (texture,slope,stoniness) is taken from map 6

Appendix B1: location codes

location	code	location	code	location	code
sea/ocean	0	GDR	10	Portugal	20
Albania	1	Greece	11	Rumania	21
Austria	2	Hungary	12	Spain	22
Belgium	3	Iceland	13	Sweden	23
Bulgaria	4	Ireland	14	Switzerland	24
Csechoslovakia	5	Italy	15	UK	25
Denmark	6	Luxemburg	16	USSR	26
FRG	7	Netherlands	17	Yugoslavia	27
Finland	8	Norway	18		
France	9	Poland	19		

Appendix B2: soil type codes

code	soil type	code	soil type	code	soil type
0	absent	80	**Planosols**	170	**Luvisols**
01	glaciers	81	Eutric Planosols	171	Haplic Luvisols
		82	Dystric Planosols	172	Ferric Luvisols
10	**Histosols**			173	Chromic Luvisols
		90	**Podzoluvisols**	174	Calcic Luvisols
20	**Leptosols**	91	Eutric Podzoluv.	175	Vertic Luvisols
21	Eutric Leptosols	92	Dystric Podzoluv.	176	Albic Luvisols
22	Dystric Leptosols	93	Stagnic Podzoluv.	177	Stagnic Luvisols
23	Rendzic Leptosols	94	Gleyic Podzoluv.	178	Gleyic Luvisols
25	Umbric Leptosols				
26	Lithic Leptosols	100	**Podzols**	180	**Acrisols**
27	Gelic Leptosols	101	Haplic Podzols	181	Haplic Acrisols
		102	Cambic Podzols	183	Humic Acrisols
30	**Arenosols**	103	Ferric Podzols		
31	Haplic Arenosols	104	Carbic Podzols	190	**Solonetz**
32	Cambic Arenosols	105	Gleyic Podzols	191	Haplic Solonetz
33	Luvic Arenosols			192	Mollic Solonetz
35	Albic Arenosols	110	**Andosols**		
36	Calcaric Arenosols	111	Haplic Andosols	200	**Solonchaks**
		114	Vitric Andosols	202	Mollic Solonchaks
40	**Regosols**			206	Gleyic Solonchaks
41	Eutric Regosols	120	**Kastanozems**		
42	Calcaric Regosols	121	Haplic Kastanozems	210	**Calcisols**
44	Dystric Regosols	122	Luvic Kastanozems	211	Haplic Calcisols
46	Gelic Regosols	123	Calcic Kastanozems		
				220	**Gypsisols**
50	**Fluvisols**	130	**Chernozems**	221	Haplic Gypsisols
51	Eutric Fluvisols	131	Haplic Chernozems		
52	Calcaric Fluvisols	132	Calcic Chernozems	230	**Anthrosols**
53	Dystric Fluvisols	133	Luvic Chernozems	233	Fimic Anthrosols
54	Mollic Fluvisols	135	Gleyic Chernozems		
60	**Gleysols**	140	**Phaeozems**		
61	Eutric Gleysols	141	Haplic Phaeozems		
62	Calcic Gleysols	142	Calcic Phaeozems		
63	Dystric Gleysols	143	Luvic Phaeozems		
65	Mollic Gleysols	144	Stagnic Phaeozems		
66	Umbric Gleysols	145	Gleyic Phaeozems		
68	Gelic Gleysols				
		150	**Greyzems**		
70	**Cambisols**	151	Haplic Greyzems		
71	Eutric Cambisols				
72	Dystric Cambisols	160	**Vertisols**		
73	Humic Cambisols				
74	Calcaric Cambisols				
75	Chromic Cambisols				
77	Gleyic Cambisols				
79	Vertic Cambisols				

Appendix B3: fixed ratios between relative proportions referring to soil type1, soil type 2 and soil type 3

% soil type1	% soil type2	% soil type3
100	0	0
90	10	0
80	20	0
80	10	10
70	30	0
70	20	10
60	40	0
60	30	10
60	20	20
50	50	0
50	40	10
50	30	20
40	40	20
40	30	30
34	33	33

Appendix B4: texture codes

texture	code	texture	code	texture	code	texture	code
0	0	1/4	4	2/4	8	3/5	12
1	1	1/5	5	3	9	4	13
1/2	2	2	6	3/4	10	4/5	14
1/3	3	2/3	7	2/5	11	5	15

0 = not indicated; 1 = coarse; 2 = medium; 3 = medium fine; 4 = fine; 5 = very fine (texture triangle: figure 3.1)

Appendix B5: slope codes

slope	code	slope	code
0	0	b/c	4
a	1	c	5
a/b	2	c/d	6
b	3	d	7

0 = not indicated; a = level (0-8%); b = sloping (8-15%); c = moderately steep (15-25%); d = steep (>25%)

Appendix B6: codes referring to stoniness and presence of a shallow lithic contact

stony/lithic phase	code
absent	0
gravelly/concretionary	1
stony	2
lithic contact < 50cm	3
gravelly + lithic contact	4
stony + lithic ocntact	5