AUSTRALIAN SOIL IDENTIFICATION SPREADSHEET (ASIS):
a program for allocating soil profiles to Australian Great Soil Groups (GSG)

Version 1.1

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ASIS User's Guide

This manual gives an introduction to fuzzy soil classification and describes the user interface to the Australian Soil Identification Spreadsheet (ASIS). The interface is in the form of dialog boxes, which are presented in one of two ways (chosen by the user) depending on whether the user is familiar or not with program. In the first case, knowledge of the spreadsheet is not required and all data entry is facilitated by the dialog boxes wherein which data is entered. In the second case, assuming the user is acquainted with the program, one single dialog box should be completed. To help the user work with this program, two examples, one from Australia and the other from the USA, are presented. The first example is for inexpert users and the other for users acquainted with the scheme. In each example, some dialog boxes along with tables of required attributes are given. At the end a glossary and an appendix are provided.

Contents

page

Introduction....................2
Fuzzy soil classification....................2
Advantages of this system....................2
The ASIS program....................3
Using ASIS....................3
An example from Australia....................4
An example from the USA....................10
Further examples....................12
Glossary....................14
References....................18
Appendix....................19

Introduction

One of the two main conventional soil classification methods used by a majority of soil scientists in Australia is the Great Soil Groups (GSG) system (Stace *et al*., 1968). In this scheme, Australian soil has been classified into 43 great groups which have been arranged in seven categories. The Australian Great Soil Groups have been popular in Australia for many years and many people are familiar with them. Therefore, the Australian Soil Identification Spreadsheet (ASIS) was designed and developed to help soil users to allocate an unknown profile quickly as well as accurately to the GSG. Since some of the 43 original groups are multiple groupings, we have expanded them to 50.

Fuzzy soil classification

Soil classification, in the traditional sense, is based on the notion that soil forms discrete, internally homogeneous units, with sharp boundaries. In this sense each soil unit can be represented by a central idea known as a typical or representative profile. This model implies that the predicted value of a soil attribute at any unsampled area is either the value for the typical profile or the mean value for the soil unit.

The problem of dealing with undefined classes and vague boundaries has led to fuzzy soil classification in which soil may belong totally, partially or not at all to soil classes. In practice, the extent of soil membership in any class is permitted from zero (no membership) to one (membership in one class only). The main feature of this system of classification is the grouping of soil individuals into classes where boundaries are not, should not or can not be, exactly defined. These diffuse classes are known as continuous classes and the system itself is called continuous classification (McBratney & De Gruijter, 1992). Allocating unknowns to fuzzy and continuous soil classes is dealt with in detail by McBratney (1994).

Advantages of this system

This system allows soil scientists to check the results of soil identification through the membership allocation; the greater the membership, the stronger the linkage to a great soil group. As this system is more flexible than conventional ones, it can transfer more and better information to users. Fuzzy soil classification is a continuous, quantitative or objective procedure in which the classes are defined in terms of membership and based on many properties simultaneously (polythetic). Additionally, as for qualitative attributes such as soil structure, this system can accommodate these subjective assessments. No special expertise is required, except for a general knowledge of soil description.

The ASIS program

The ASIS is based on the fuzzy *k*-means with extragrades algorithm. Fuzzy *k*-means with extragrades has been applied to permit variation in the distance dependence for membership in the outlier group recognized by De Gruijter and McBratney (1988).

The implementation on the Macintosh and PC makes the technique for generalised fuzzy *k*-means available for soil profile identification for the first time to everyday users. ASIS which is distributed on an 1.44 MB floppy diskette requires an Apple Macintosh or Windows compatible PC with Microsoft Excel version 5.0 installed.

Using ASIS

ASIS requires inputs to be coded and soil colour attributes transformed in a particular manner (Mazaheri *et al*., 1995). Twenty attributes are needed: topsoil and subsoil texture for texture profile; topsoil salinity; subsoil salinity; topsoil organic matter %; subsoil pH (1:5 H_2O); subsoil structure; subsoil mottling; subsoil clay %; bleaching of A2 (E) horizon (if present); concretions; crust; hardpan; topsoil calcium carbonate; subsoil (pedological) calcium carbonate; subsoil gypsum; pedological subsoil; alluvial layer; parent material and subsoil colour.

For allocation of the profile to one of the texture profile classes of uniform, gradational and duplex (Northecote, 1979), the topsoil, midpoint (A2, A3, A/B or B1, if present) and subsoil texture should be determined. ASIS can allocate the profile automatically to the texture profile. Topsoil and subsoil salinity should be expressed in $dS\ m^{-1}$ in a 5:1 water:soil extract. Acidity or pH should be measured in 1:5 soil:water ratio. As organic matter in soil is not usually measured, it can be calculated by approximate conversion that assumes soil organic matter contains generally 57 % carbon. Therefore,

$$\%\ O.M. = \%\ O.C. \infty\ 100/57$$

Moist soil colour is quantified and transformed automatically within the spreadsheet, provided the Munsell hue, chroma and value are entered. The final result is an allocation to one or more GSG. The membership values are displayed and may be printed out. As an illustration of ASIS two example are presented as follows.

An Example from Australia–step-by-step guide

The following soil description is of a profile from the Lower Namoi Valley in New South Wales, Australia, (McGarry *et al.*, 1989). The soil has a texture contrast and is formed on alluvial sediment and clay deposits.

Horizon	Depth (cm)	Description
A1	0–25	Dark brown (7.5YR 3/2); sandy loam; massive; pH=7; EC=0.08 dS m^{-1} ; OM%=2.2; clay %=9;
A2 (E)	25–42	Dark brown (7.5YR 4/4); sandy loam; massive; sporadically bleached; pH=7.2; EC=0.06 dS m^{-1}; OM%=1; clay%=11;
B2	42–125	Yellowish red (5YR 4/8); light clay; medium mottles; moderate columnar structure; pH=7; EC=0.07 dS m^{-1}; OM%=1; clay%=45;
C	>125	Reddish brown (5YR 5/4); medium mottles; weak columnar structure; few medium calcareous nodules; pH=7.7; EC=0.3 dS m^{-1}; OM%=0.7; clay%=29.

To allocate this profile to a GSG using ASIS, select from main menu dialog box (Fig. 1) “Soilwizard” or “Enter Attributes”. Soilwizard is a step-by-step data entry procedure with each step explained. “Enter Attributes” is for more experienced users. In this example, as an inexpert user, the “Soilwizard” is selected. A selection of dialog boxes are presented in this step-by-step example. The initial entry is for the soil describer and identifier’s name along with the profile location (Fig. 2). By clicking on “Next” the texture type dialog box appears (Fig. 3). As the soil is not organic, “Other” and “Next” are selected. Regarding A1 and B2 horizons, “Sandy loam” (Fig. 4) and “Light Clay” groups are chosen respectively. The EC of both topsoil and subsoil is in the “0-0.63 dS/m” class (Fig. 5). As O.M % of

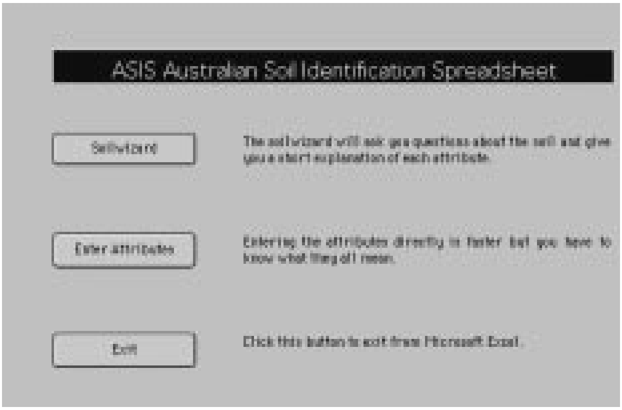

Fig. 1. Main menu dialog box

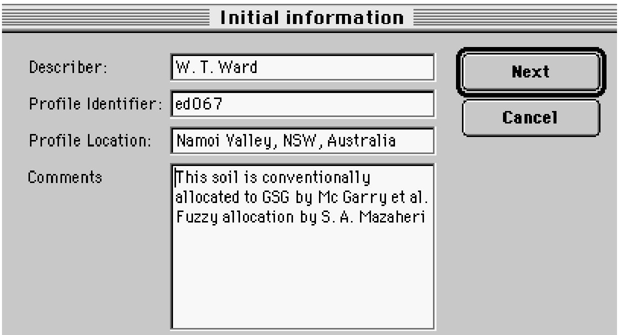

Fig. 2. Initial dialog box

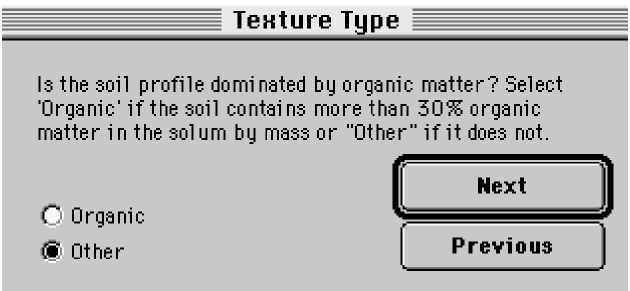

Fig. 3. Texture type dialog box.

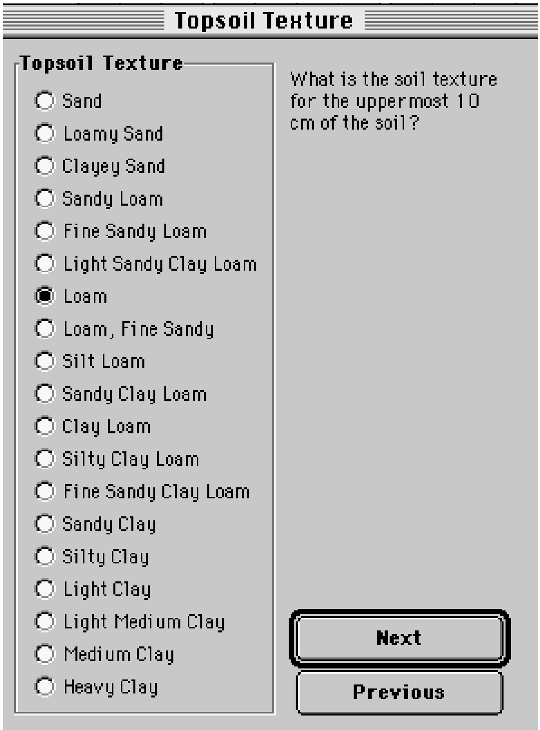

Fig. 4. Texture dialog box

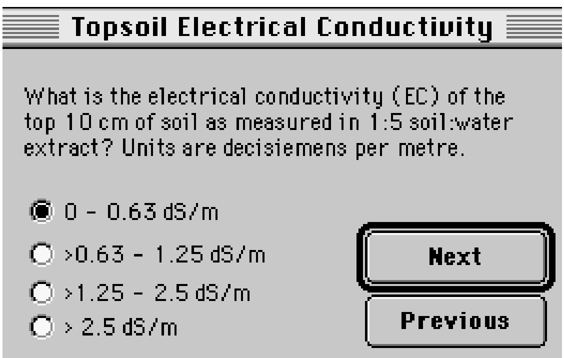

Fig. 5. Topsoil salinity dialog box

topsoil is less than 2.5, the class “0-2.5” is selected and for subsoil acidity, pH=7 is entered. Soil structure is moderate and the solum contains mottling (up to 30 %). For the subsoil clay %, the value 45 is entered (Fig. 6) and for the A2 (E) horizon "sporadically bleached A2" horizon is selected. The above soil profile description shows no concretions (Fig. 7), hardpan, gypsum, topsoil and subsoil calcium carbonate (Fig. 8) or an alluvial layer, so "Next" is selected in each case. The soil has a pedological subsoil in that there is a well-developed B2 horizon. As the soil is presumably formed from sandstone, “Other” is selected for parent material. The moist subsoil colour is 5YR 4/8 and 5YR for hue, 4 for value and 8 for chroma (Fig. 9)

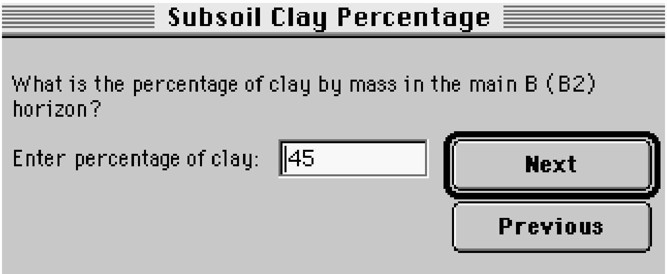

Fig. 6. Clay percentage dialog box

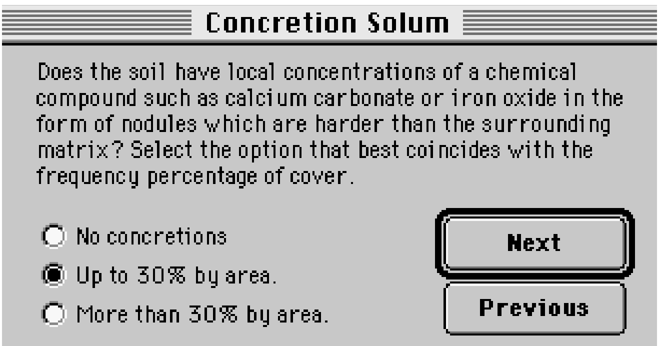

Fig. 7. Concretions dialog box

should be entered before selecting “OK”. Table 1. gives a summary of all the above attributes and their classes. After a short time membership to one

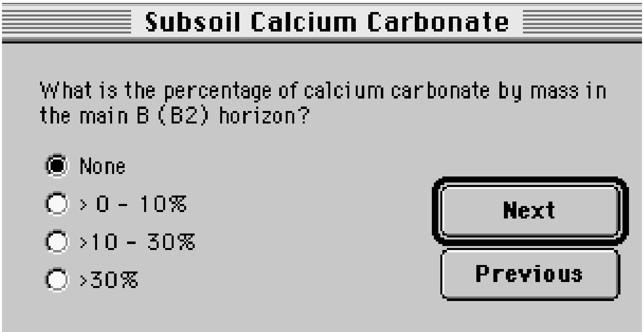

Fig. 8. Subsoil calcium carbonate dialog box

or more of the GSG will will be displayed (Fig. 10).

Originally, this soil example was allocated to the GSG class of red-

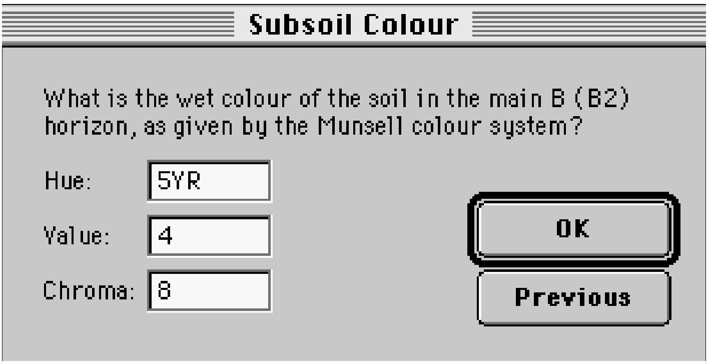

Fig. 9. Subsoil colour dialog box

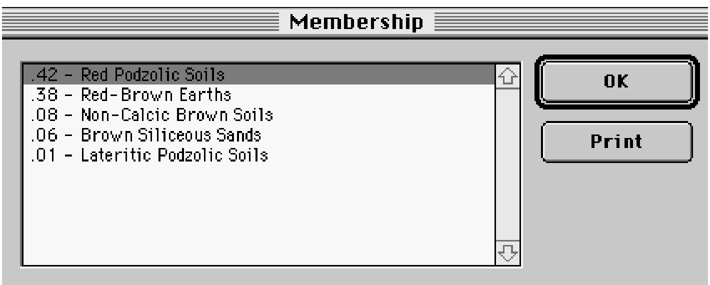

Fig. 10. Membership dialog box

brown earth but in the fuzzy classification it has partial membership in different groups of which the three main ones are: red podzolic soil (0.42), red-brown earth (0.38) and non-calcic brown soil (0.08).

Soil attributes	**Attribute classes**
texture profile	duplex
topsoil salinity	EC<0.63 dS m^{-1}
subsoil salinity	EC<0.63 dS m^{-1}
topsoil organic matter	<2.5 %
subsoil pH	7
subsoil structure	moderate
solum mottling	present
subsoil particle size	clay %=45
A2 (E) horizon	present
A2 (E) bleached	sporadic
concretions	absent
crust	absent
hardpan	absent
topsoil $CaCO_3$	absent
subsoil $CaCO_3$	absent
gypsum	absent
alluvial layer	absent
pedological subsoil layer	present
parent material	other
subsoil colour (hue)	5YR
subsoil colour (value)	4
subsoil colour (chroma)	8

Table 1. Soil attributes and their classes for soil example 1

An example from the USA

This soil is from Reeves County, Texas, USA (Soil Taxonomy, 1975) and is formed from calcareous, gypsiferous alluvium on a level plain with the following description.

Horizon	Depth (cm)	Description
A11	0–1	Brown (10YR 4.5/3); loam; platy crust; slightly hard (hard), very friable (moist); strongly effervescent with acid; $CaCO_3$ %=12; EC=2.5 dS m^{-1}; pH=8.1; clay %=26;
A12	1–5	Brown (10YR 4.5/3); loam; very friable (moist); strongly effervescent with acid; $CaCO_3$ %=12; EC=3.8 dS m^{-1}; pH=8.1; clay %=30;
A13	5–13	Brown (10YR 4.5/3); loam; weak to moderate fine subangular blocky structure; hard; friable; strongly effervescent with acid; $CaCO_3$ %=12; EC=4 dS m^{-1}; pH=8.2; clay %=29.2;
B21ca	13–33	Light brown (7.5YR 5/4); silty loam; weak to moderate fine subangular block structure; friable; strongly effervescent with acid; few concretions, film and threads of calcium carbonate; $CaCO_3$ %=19; EC=9.2 dS m^{-1}; pH=8.2; clay %=35;
B22ca	33–56	Light brown (7.5YR 5/4); clay loam; weak fine subangular blocky; consistence; calcium carbonate as above; EC=29 dS m^{-1}; pH=8; clay %=35;

C	>56	Very pale brown (10YR 8/3); weakly cemented gypsiferous calcareous loam; $CaCO_3$%=19; very hard (dry); friable and somewhat brittle; EC=21.3 dS m^{-1}; pH=7.8; clay%=41;

On the supposition that users are acquainted with the definitions and explanations, the above soil profile will be allocated to the GSG system using the alternative means of data entry, “Enter Attributes”. After entering the required initial information (Fig. 11), clicking on “Next” gives the Soil Data display (Fig. 12). The texture profile is uniform and as the topsoil and subsoil are highly saline, the salinity class “>2.5 dS/m” should be selected. The class 10-30 % $CaCO_3$ for topsoil and subsoil calcium carbonate and for O.M the class less than 2.5 % should be chosen. Soil structure is moderate and soil profile contains some concretions as well as some gypsum and a crust exists on the surface. There are no mottles, A2 horizon, hardpan or an alluvial layer. Clay content is 35 % and the subsoil colour is 7.5YR 5/4. Table 2 gives a summary of the soil attributes and their classes.

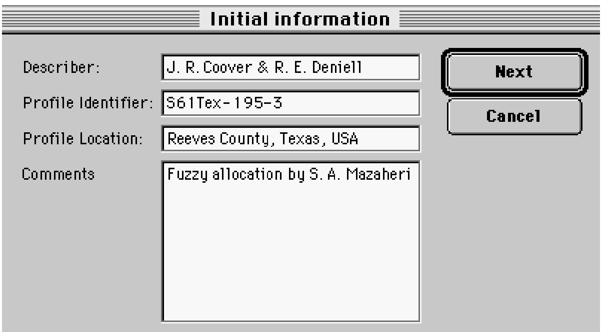

Fig. 11. Initial information dialog box

After completing the Soil Data sheet (Fig.12),by clicking on “OK” the membership allocattion will be displayed (Fig 13). The soil was allocated to the class of Gypsiorthid in Soil Taxonomy and to the fuzzy classification as an extragrade (0.61). This example shows how the system works with soil not common in Australia. There are great dissimilarities between the GSG centroids and this soil which has considerable membership in the extragrade group. The remaining small membership is distributed among various GSG like arid solonchak, rendzina, red earth and krasnozem.

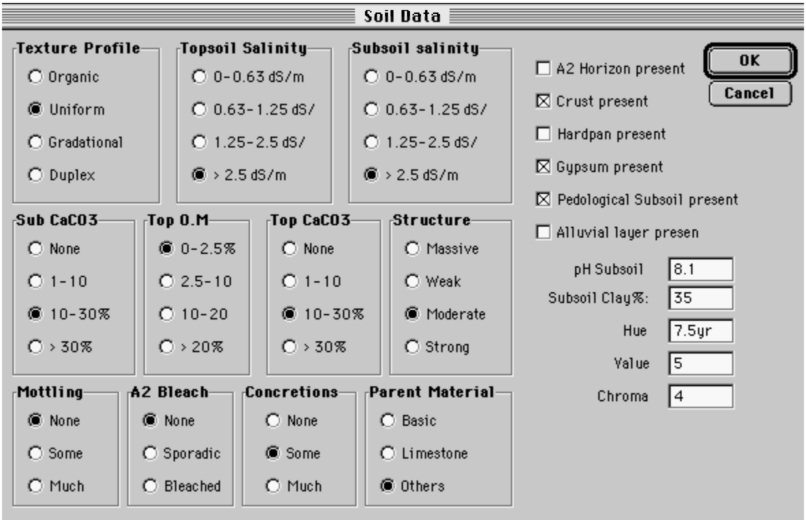

Fig. 12. "Enter Attributes" dialog box.

Fig. 13. Membership dialog box

Further examples

Further examples may be found in Mazaheri ***et al***. (1995).

Soil attributes	Attribute classes
texture profile	uniform
topsoil salinity	EC>2.5 dS m^{-1}
subsoil salinity	EC>2.5 dS m^{-1}
topsoil organic matter	<2.5 %
subsoil pH	8.1
subsoil structure	moderate
solum mottling	absent
subsoil particle size	clay %=45
A2 (E) horizon	absent
concretions	present
crust	present
hardpan	absent
topsoil $CaCO_3$	10–30 %
subsoil $CaCO_3$	10–30 %
gypsum	present
alluvial layer	absent
pedological subsoil layer	present
parent material	other
subsoil colour (hue)	7.5YR
subsoil colour (value)	5
subsoil colour (chroma)	4

Table 2. Soil attributes and their classes for soil example2

To help users become acquainted with the attributes needed, and related codes, the following glossary is provided.

Glossary

Soil Texture A measure of the behaviour of a handful of soil when moistened and kneaded into a bolus and then pressed out between thumb and forefinger. Nineteen grades of texture, such as sand, loamy sand and silt loam, are commonly recognised (Table 3).

Texture Groups The nineteen texture grades are arranged in six groups as shown in column 1 Table 3.

Topsoil For convenience this is defined here as the uppermost 10 cm of the soil. It could be part ofthe A1 horizon or plow layer (Ap layer).

Subsoil The underlying layer which is immediately beneath any A horizon. It is the main B horizon (usually the B2) and is often encountered between 30-60 cm.

Solum The upper and most weathered part of the soil profile: the A and B horizons.

Texture Profile Change of texture with depth of soil. In ASIS the texture profile is automatically calculated from the texture entry of the topsoil, subsoil and a point between if a B1 or an A2 (E) horizon that increases in clay from the A1 is present. Four texture profiles have been recognised as follows (Northcote, 1979).

0. Organic-soil profile dominated by organic matter. Soil which has 20 % or more organic matter and less than 15 % clay or 30 % or more organic matter and more than 15 % clay in the surface 30 cm has an organic texture profile, e.g. acid peat and neutral-alkaline peat.

1. *Uniform*-soil with no clearly defined texture boundary and the equivalent of one texture group, e.g. black earth and chernozem.

2. *Gradational*-soil showing increasingly finer texture grades on passing down the profile e.g. krasnozem and red earth.

3. *Duplex*-soil profile with a texture contrast of the equivalent of 1.5 texture groups or greater between the A and B horizons, e.g. red-brown earth and yellow podzolic soil.

Topsoil Salinity (1:5 water) Electrical conductivity (EC) in the surface 10 cm of soil profile (topsoil) in dS m^{-1}. Four salinity classes have been designated as follows:

0. soil with EC<0.63 dS m^{-1} , e.g. podzol and chocolate soil.

1. soil having EC 0.63–1.25 dS m^{-1} , e.g. wiesenboden.

2. soil having EC 1.25–2.5 dS m^{-1} , e.g. desert loam.

FIELD TEXTURE GROUPS	RIBBON LENGTH (mm)	COHERENCE	FEEL	OTHER FEATURES	TEXTURE GRADE		APPROX. CLAY %
1 ***The Sands***	Nil	Nil	Sandy	Single sand grains adhere to fingers	**1**	**Sand (S)**	Commonly <5
	5	Slight	Sandy	Discolours fingers with an organic stain	**2**	**Loamy Sand(LS)**	5–10
	5–15	Slight	Sticky	Sand grains stick to fingers and discolour with a clay stain	**3**	**Clayey Sand (CS)**	5–10
2 ***The Sandy Loams***	15–25	Just Coherent	Very Sandy	Medium Sand readily visible	**4**	**Sandy Loam(SL)**	10–20
	15–25	Just Coherent	Very Sandy	Fine Sand may be heard	**5**	**Fine Sandy Loam (FSL)**	10–20
	20–25	Strong	Sandy	Medium sand easily visible	**6**	**Light Sandy Clay Loam (SCL-)**	15–20
3 ***The Loams***	about 25	Coherent	Spongy and Greasy	No obvious sandiness	**7**	**Loam(L)**	25
	about 25	coherent	slightly spongy	Fine sand	**8**	**Loam Fine Sandy (LFsy)**	25
	about 25	coherent	Smooth	Silky; very smooth when manipulated	**9**	**Silt Loam (SiL)**	25 (>25% Silt)
	25–40	Strong	Sandy	Medium sand in fine matrix	**10**	**Sandy Clay Loam (SCL)**	20–30
4 ***The Clay Loams***	40–50	Strong	Smooth	No obvious sand grains	**11**	**Clay Loam (CL)**	30–35
	40–50	Coherent	Smooth	Silky feeling	**12**	**Silty Clay Loam (SiCL)**	30–35 (>25% Silt)
	40–50	Coherent	Smooth & Sandy	Fine sand can be felt and heard	**13**	**Fine Sandy Clay Loam (FSCL)**	30–35
5 ***The Light Clays***	50–75	Coherent	Plastic	Fine to medium sand	**14**	**Sandy Clay (SC)**	35–40
	50–75	Coherent	Plastic	Smooth and silky	**15**	**Silty Clay (SiC)**	35–40 (>25% Silt)
	50–75	Coherent	Plastic	Smooth with slight resistance to shearing	**16**	**Light Clay (LC)**	35–40
	>75	Coherent	Plastic	Smooth with a little resistance to shearing	**17**	**Light Medium Clay (LMC)**	40–45
6 ***The Medium & Heavy Clays***	>75	Coherent	Plastic	Fair resistance to shearing	**18**	**Medium Clay (MC)**	45–55
	>75	Coherent	Plastic	Firm resistance to shearing	**19**	**Heavy Clay (HC)**	>50

Table 3. Field texture groups and texture grades

3. soil with EC>2.50 dS m^{-1} , e.g. solonchak.

Subsoil Salinity (1:5 water) Electrical conductivity of the subsoil in dS m^{-1} . Four salinity classes have been defined as follows:

0. soil with EC<0.63 dS m^{-1} in, e.g. red and yellow podzolic soil.

1. soil having EC 0.63–1.25 dS m^{-1}, e.g. solonized brown soil and black earth.

2. soil having EC 1.25–2.5 dS m^{-1} , e.g. solonetz and humic gley.

3. soil with EC>2.50 dS m^{-1} , e.g. solonchak and desert loam.

Topsoil Organic Matter % Percentage of organic matter in topsoil. Four levels of organic matter are given.

0. soil with O.M.<2.5 %, e.g. yellow earth and earthy sand.

1. soil with O.M. 2.5–10 %, e.g. euchrozem and prairie soil.

2. soil with O.M.10–20 %, e.g. humus podzol and alpine humus soil.

3. soil with O.M.>20 %, e.g. peaty podzol and acid peat.

Subsoil Acidity (pH) 1:5 water pH value of the subsoil. It is usually within the range of 3–11.

Subsoil Structure A classification on the basis of the degree of structure development. Four grades of structure recognised as follows:

0. *Massive*–soil without observable aggregation, e.g. siliceous sand and red earth.

1. *Weak*–soil with <1/3 pedality and poor and barely observable aggregation, e.g. earthy sand.

2. *Moderate*–soil with 1/3-2/3 pedality and moderately aggregation, e.g. yellow podzolic soil.

3. *Strong*–soil with >2/3 pedality and quite aggregation, e.g. krasnozem.

Solum Mottling Areas of different colour or shades of colour interspersed with the dominant colour. Three options have been recognised:

0. soil without mottling in profile, e.g. calcareous sand and desert loam.

1. soil with some mottling in profile, e.g. grey-brown podzolic and red-brown earth .

2. soil with much mottling in profile, e.g. yellow podzolic soil and humic gley.

Subsoil Clay % Percentage of clay in subsoil. This may be estimated from the field texture (Table 3) or a particle size analysis (PSA).

A2 (E) Horizon A pale horizon in which the main features are loss of clay, iron or aluminium, with the resultant concentration of quartz and silt sizes particles. Four options have been given:

0. soil without A2 (E) horizon, e.g. solonchak and earthy sand.

1. soil with an unbleached A2 (E) horizon e.g. some red podzolic soil.
2. Sporadic bleach A2 (E) horizon–soil with irregular bleached portions, e.g. desert loam.
3. Conspicuous bleached A2 (E) horizon–soil in which 80 % or more of the A2 (E) is bleached, e.g. podzol and soloth.
Concretions Local concentrations of chemical compounds such as calcium carbonate or iron oxide in the form of nodules. Three options have been given:
0. soil without concretions in the profile, e.g. podzol and non-calcic brown soil.
1. soil with some concretions in the profile, e.g. prairie soil and red podzolic soil.
2. soil with many concretions in the profile, e.g. lateritic podzolic soil.
Crust A surface layer, ranging in thickness from a few millimetres to a few centimetres, that is usually compact, hard and brittle when dry. There are two options for this attribute:
0. soil without a crust, e.g. chernozem and krasnozem.
1. soil with a crust, e.g. desert loam and solonchak.
Hardpan A silica cemented red or brown soil layer in the lower A or B horizon. There are two options for this attribute:
0. soil without a hardpan, e.g. red podzolic soil and red-brown earth.
1. soil with a hardpan, e.g. red and brown hardpan soil.
Topsoil $CaCO_3$ % Percentage of calcium carbonate in the topsoil. Four classes of calcium carbonate have been recognised:
0. soil without calcium carbonate, e.g. solonetz and krasnozem.
1. soil with $CaCO_3$ =1–10 %, e.g. red calcareous soil and rendzina.
2. soil with $CaCO_3$ =10–30 %, e.g. grey-brown calcareous soil.
3. soil with $CaCO_3$>30 %, e.g. calcareous sand.
Subsoil $CaCO_3$ % Percentage of calcium carbonate in the subsoil. Four classes of calcium carbonate have been recognised:
0. soil without calcium carbonate, e.g. podzol and krasnozem.
1. soil with $CaCO_3$ =1-10 %, e.g. red-brown earth soil and desert loam.
2. soil with $CaCO_3$=10-30 %, e.g. calcareous red earth and solonchak.
3. soil with $CaCO_3$>30 %, e.g. calcareous sand.
Gypsum Two options have been given for gypsum in the solum:
0. soil without gypsum, e.g. black earth and chernozem.
1. soil with gypsum, e.g. desert loam and solonchak.
Pedological Subsoil A subsoil showing pedological development expressed as some combination of colour, texture or structure contrast with other

layers. Two options have been recognised:
0. soil without a pedological subsoil, e.g. alluvial soil and lithosol.
1. soil with a pedological subsoil, e.g. red and yellow podzolic soil.
Alluvial Layer A recently deposited alluvium exhibiting essentially no horizon development. Two options have been given:
0. soil without an alluvial layer, all soil groups but alluvial soil.
1. soil with an alluvial layer, alluvial soil.
Parent Material The unconsolidated and more or less weathered material from which soil horizons are developed by pedogenic processes. Three kinds of parent material have been recognised:
0. basic material such as basalt.
1. limestone and other calcareous material.
2. others containing appreciable quartz, e.g. granite.
Subsoil Colour An attribute which is defined in terms of hue, value and chroma using the Munsell soil colour charts (1954).
Hue–Caused by light of certain wavelengths and changes with wavelength. The hue of a colour indicates its relation to Red, Yellow, Green, Blue and Purple.
Value–The relative lightness of colour and is approximately a function of the square root of the total amount of light.
Chroma–The relative purity, strength, or saturation of a colour.

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Appendix

The method applied to determine the class membership rests on the work by De Gruitjer & McBratney (1988), McBratney & De Gruitjer (1992), and McBratney (1994).

The optimal classification produced from an n (individual) ∞ p (attributes) data matrix **X** is defined by the following parameters

k	the number of classes;
ϕ	the fuzziness exponent, the larger the value of ϕ the fuzzier the classification, 1< ϕ < i.e. the more likely the mem– bership for any individual will aproach 1/(*k*+1), where *k* is the number of classes;
α	a parameter that defines the contribution of the outlier or extragrade class, 0<α<0.5;
C	with elements (Ccv) is a *k* ∞ p matrix of class centres, Ccv denoting the value of the centre of class c for variable v;
E	is the p ∞ p samplevariance-covariance matrix of **X**, the inverse of which is used in calculating distances from a new individual to the k centroids; this is an estimate of the population variance-covariance matrix.

The allocation is achieved by evaluating the two-part equation

$$m_c = \frac{D_c^{-2/(\phi-1)}}{\sum_{j=1}^{k} D_j^{-2/(\phi-1)} + \left(\frac{1-\alpha}{\alpha}\sum_{j=1}^{k} D_j^{-2}\right)^{-1/(\phi-1)}} \qquad c=1,\ldots,k \qquad (1)$$

$$m^* = \frac{\left(\frac{1-\alpha}{\alpha}\sum_{j=1}^{k} D_j^{-2}\right)^{-1/(\phi-1)}}{\sum_{j=1}^{k} D_j^{-2/(\phi-1)} + \left(\frac{1-\alpha}{\alpha}\sum_{j=1}^{k} D_j^{-2}\right)^{-1/(\phi-1)}} \qquad (2)$$

The first part (1) calculates the membership, m_c, in each normal class and the second one (2) calculates the membership, m*, in extragrade classes. Evaluation of these equations requires the parameters and two matrices given above and a description of a new individual, a vector, **x**, of length p. The equations cannot be evaluated until the generalized or Mahalanobis' squared distance, D^2c, from each centroid to the new individual is first calculated by

$D^2c = (\mathbf{x} - \mathrm{c}c)^T \mathbf{E}^{-1} (\mathbf{x} - \mathrm{c}c)$, c=1,.......*k*,

where c*c* is the vector of length p describing the *c*th centroid and **E** is the sample covariance matrix of **X**.

In this study *k*=50 (the number of pre-existing classes) and the value of other parameters were defined as following:

ϕ=1.08 and α=0.01,

which were selected by trial and error trying a range of 1.01-1.15 for ϕ and 0.001-0.05 for α. Finally, the above values showed the best and most reasonable balance between continuous soil variation and soil classes.