

# A world dataset of derived soil properties by FAO–UNESCO soil unit for global modelling

N.H. Batjes

**Abstract.** A standardized dataset of derived soil properties for the 106 soil units considered on FAO–UNESCO's 1:5 million scale Soil Map of the World is presented. It was derived from a statistical analysis of the 4353 soil profiles held in the WISE (World Inventory of Soil Emission) database, which was developed at the International Soil Reference and Information Centre (ISRIC) for the geographic quantification of soil factors that control processes of global change. Median values are presented by soil unit for selected soil properties, including: pH(H<sub>2</sub>O); organic carbon content; cation exchange capacity; sum of exchangeable Ca<sup>2+</sup>, Mg<sup>2+</sup> and K<sup>+</sup>; exchangeable sodium percentage; bulk density; total porosity; available water capacity; soil drainage class; and gravel content class. Medians for these variables are presented both for the topsoil (0–30 cm) and subsoil (30–100 cm), where applicable. The data set can help to refine ratings for soil quality in global environmental models pending the availability of comprehensive georeferenced databases on soil and terrain resources such as SOTER, the World Soil and Terrain Database. In a Geographical Information System (GIS) it can be linked to the units shown on the digital Soil Map of the World through the legend code.

**Keywords:** Soil properties, databases, models, World

## INTRODUCTION

The availability of geographic databases of biophysical factors, such as vegetation cover, climate, landform and soil properties, as well as socioeconomic factors, determines extrapolation and modelling capabilities at the global level (Prentice *et al.*, 1992; Hagen *et al.*, 1993; Zuidema *et al.*, 1995; Neave *et al.*, 1995). These databases are needed at scales that reflect the effect on the regional and global processes that are relevant to modelling goals (Wessman, 1992). In spite of the importance of proper selection and quantification of soil factors for use in global models there are only a few published studies on this topic. Often, current soil datasets are based on limited profile data and coarse resolution spatial data (e.g. Zobler, 1986; Webb *et al.*, 1991). Thus it remains crucial to update and expand soil databases specifically developed to support sustainable development at the continental level (Oldeman & Van Engelen, 1993; Arnold, 1995; Madsen & Jones, 1995).

This paper presents a data set of derived soil properties for use in global models at the scale 1:5 M. It was derived from a statistical analysis of the soil horizon data currently held in WISE. The integrated WISE database consists of two parts, a spatial component and an attribute data component (Batjes & Bridges, 1994; Batjes *et al.*, 1995). The attribute data consist of soil profiles considered to be representative for the 106 soil units shown on a  $\frac{1}{2}^\circ$  latitude by  $\frac{1}{2}^\circ$  longitude grid-version of FAO's edited digital Soil Map of the World (Food and Agriculture Organization, 1991). The derived dataset can be linked to the Soil Map of the World using the soil unit codes (Fig. 1).

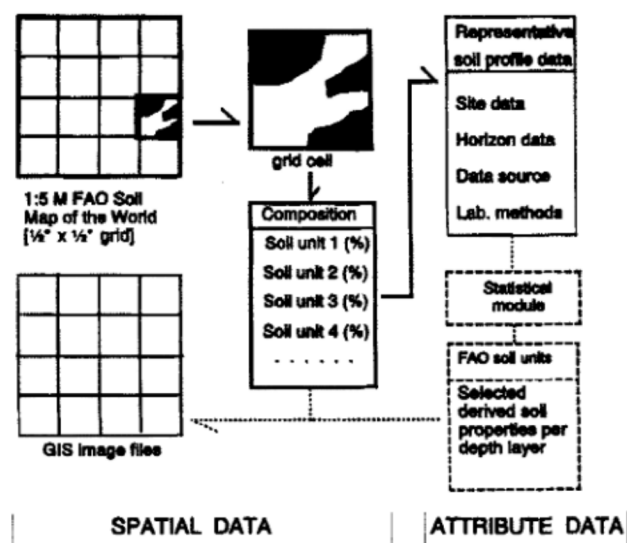


Fig. 1. Schematic representation of the spatial and attribute data of the WISE database.

Firstly, the data sources and soil attributes considered are discussed. Secondly, the derived soil dataset is presented. Finally, its possible uses in global environmental studies are discussed and future developments outlined.

## METHODOLOGY

### Source of data

Profiles in WISE were compiled from five sources: ISRIC's Soil Information System; FAO's Soil Database; the digital

**Table 1.** List of FAO-UNESCO soil units represented in WISE

FAO soil unit †
A: Acrisols
Af = 124 Ag = 21 Ah = 71 Ao = 68 Ap = 36
B: Cambisols
Bc = 30 Bd = 91 Be = 140 Bf = 47 Bg = 49 Bh = 49 Bk = 115 Bv = 45 Bx = 17
C: Chernozems
Cg = 0 Ch = 24 Ck = 32 Cl = 14
D: Podzoluvisols
Dd = 5 De = 5 Dg = 1
E: Rendzinas
E = 35
F: Ferralsols
Fa = 24 Fh = 50 Fo = 85 Fp = 8 Fr = 44 Fx = 50
G: Gleysols
Gc = 15 Gd = 63 Ge = 90 Gh = 33 Gm = 47 Gp = 4 Gx = 7
H: Phaeozems
Hc = 25 Hg = 18 Hh = 73 Hl = 92
I: Lithosols
I = 8
J: Fluvisols
Jc = 141 Jd = 32 Je = 167 Jt = 26
K: Kastanozems
Kh = 13 Kk = 14 Kl = 1
L: Luvisols
La = 28 Lc = 109 Lf = 114 Lg = 101 Lk = 145 Lo = 148 Lp = 12 Lv = 17
M: Greyzems
Mg = 1 Mo = 7
N: Nitosols
Nd = 25 Ne = 43 Nh = 13
O: Histosols
Od = 35 Oe = 11 Ox = 4
P: Podzols
Pf = 2 Pg = 15 Ph = 20 Pl = 11 Po = 29 Pp = 12
Q: Arenosols
Qa = 12 Qc = 184 Qf = 89 Ql = 36
R: Regosols
Rc = 28 Rd = 35 Re = 54 Rx = 2
S: Solonchaks
Sg = 17 Sm = 5 So = 42
T: Andosols
Th = 90 Tm = 28 To = 16 Tv = 31
U: Rankers
U = 8
V: Vertisols
Vc = 152 Vp = 148
W: Planosols
Wd = 10 We = 22 Wh = 1 Wm = 8 Ws = 21 Wx = 0
X: Xerosols
Xh = 20 Xk = 19 Xl = 88 Xy = 8
Y: Yermosols
Yh = 9 Yk = 13 Yl = 17 Yt = 1 Yy = 15
Z: Solonchaks
Zg = 21 Zm = 3 Zo = 47 Zt = 2

†For definitions of soil unit codes see Food and Agriculture Organization (1974).

dataset of the National Soil Conservation Service of the United States of America (NRCS); profile descriptions chosen by national soil survey organisations to be representative of the units of the Soil Map of the World present in their countries; and data gathered from survey monographs held in ISRIC's library. Special attention was given to the systematic compilation of the data and recording of the laboratory methods by which the analytical results were obtained.

The Food and Agriculture Organization's 1974 classification of the 4353 profiles in WISE (representing a total of 20 986 horizons) is presented in Table 1. The soil profiles come from: Africa (1799); South West and North Asia (522); South

East Asia (553); Australia and the Pacific Islands (122); Europe (492); North America (266); and South America and the Caribbean (599). Complete datasets are not always available for each horizon for the soil attributes under consideration. Thus the number of samples for each of these attributes will vary between soil units and with the depth range.

#### Soil attributes

The following soil attributes are considered in this study. Soil pH(H<sub>2</sub>O) was measured in a soil:water solution varying from 1:1 to 1:5 (see Batjes 1995a). Organic carbon (OC) content was determined according to Walkley/Black (see Nelson & Sommers 1982). Cation exchange capacity (CEC) was measured in a 1M NH<sub>4</sub>OAc solution buffered at pH 7. Exchangeable sodium percentage (ESP) is given as % of CEC. Bulk density was determined according to the core-method (Van Reeuwijk 1993). Total porosity was derived from data on median bulk density and an assumed particle density of 2.65 g/cm<sup>3</sup>. The soil moisture range considered in determining available water capacity (AWC) is from pF 2.5 to pF 4.2 (≈ 33 to 1500 kPa), conforming with USDA standards (Soil Survey Staff, 1993). Drainage class is expressed in the classes of FAO (1990). Gravel content refers to the % of fragments > 2 mm.

#### Data analysis

Data analysis for quantitative variables involved three stages. Firstly, the horizon data for the considered attributes were extracted from WISE to a working file. Secondly, these datasets were screened with respect to the type of methods used for the original analyses (e.g. CEC in 1M NH<sub>4</sub>OAc at pH 7). Thirdly, the homogenized sets were subdivided into samples from the topsoil (0–30 cm) and samples from the subsoil (30–100 cm). Finally, statistical analyses were made for each of the datasets with commercially available software (STATISTIX 1994).

Drainage class for each profile was first assigned a value, ranging from 1 (very poorly drained) to 7 (excessively drained), on the basis of field-observed drainage condition classified according to FAO Guidelines (1990). The median value for drainage class was then computed by FAO-UNESCO second level soil unit. Finally, this value was translated into the final (weighted) drainage class for the soil unit, using the classes of FAO (1990).

The percentage of fragments > 2 mm was analysed statistically by FAO-UNESCO soil unit. In view of the large spatial variability in gravel content, the medians were converted to classes (after Food and Agriculture Organization, 1990).

## RESULTS AND DISCUSSION

#### Derived soil data

Generalization of measured soil (profile) data for use in global models involves the transformation of variables that show a marked spatial variability. No attempt was made in this study to establish the location of individual profiles because each profile was collected to be representative for a particular Food and Agriculture Organization's 1974 soil unit. As such, differences in landform, parent material, land use history and native vegetation are not considered explicitly. Table 2 may serve as an example to illustrate the large spatial variability

Table 2. Variability in organic carbon content for selected FAO soil units†

FAO-74	N	MIN	QU1	MED	QU3	MAX
<b>Acrisols</b>						
A	769	0.02	0.55	1.04	2.15	33.14
Af	294	0.02	0.46	0.75	1.24	6.46
Ag	53	0.16	0.55	1.10	3.89	33.14
Ah	169	0.53	1.46	2.30	3.72	30.42
Ao	159	0.10	0.46	0.78	1.39	13.84
Ap	94	0.11	0.48	1.04	1.81	7.20
<b>Cambisols</b>						
B	1270	0.04	0.55	1.05	2.24	43.00
Bc	61	0.22	0.56	1.02	1.82	5.26
Bd	231	0.07	0.94	1.94	4.00	43.00
Be	289	0.04	0.49	0.90	1.65	10.10
Bf	106	0.16	0.55	0.95	1.62	6.06
Bg	112	0.10	0.59	0.91	1.87	20.30
Bh	98	0.25	1.78	3.04	5.68	36.90
Bk	240	0.04	0.40	0.63	1.05	21.57
Bv	83	0.22	0.59	0.84	1.45	6.45
Bx	50	0.09	0.93	1.80	3.77	43.00
<b>Ferralsols</b>						
F	613	0.12	0.79	1.33	2.33	23.10
Fa	53	0.40	0.96	1.73	2.67	6.96
Fh	108	0.60	1.37	2.27	3.71	8.72
Fo	202	0.15	0.67	1.12	2.02	23.10
Fp	18	0.40	0.93	1.29	1.99	3.16
Fr	105	0.23	0.67	1.19	1.90	6.67
Fx	127	0.12	0.61	1.00	1.65	10.20

†Data shown are for the topsoil (0–30 cm). Organic carbon content is expressed in % weight. N is number of samples per FAO–UNESCO soil unit, MIN the minimum, QU1 the first quartile, MED the median, QU3 the third quartile, and MAX the maximum for the considered datasets.

ity in organic carbon content within selected soil units (see also Batjes, 1995a, 1996).

If there were no measured data for a specific combination of FAO–UNESCO second level unit, the median for the corresponding first level soil unit, depth interval and soil attribute were substituted in the dataset (Table 3). This derived file of median soil properties can be linked to the map units shown on the digital versions of the Soil Map of the World through the soil unit code. It can then be used in GIS-based studies of soil gaseous emission potentials, soil vulnerability to pollution, and crop productivity at the global level depending on the availability of more detailed data. The dataset is considered appropriate to improve current rating schemes for soil quality in global models which, of necessity, were largely based on expert-judgement (Bachelet & Neue, 1993; Bouwman *et al.*, 1993; Leemans & Van den Born, 1995; Luyten, 1995) or limited soil profile data sets (Chadwick & Kuylenstierna, 1990; Webb *et al.*, 1991).

#### Spatial data

Small scale maps encompass a marked degree of data integration, the aim being to simplify the geographical distribution of soils to a regionally representative pattern of dominant soils. In the context of the WISE project, the predictive use of the digitized, 1:5 M scale Soil Map of the World (Food and Agriculture Organization, 1991; Food and Agriculture Organization, 1995) was of significant importance. The areas of soil units depicted on this map were used as a cartographic basis for the preparation of a  $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$  resolution database, corresponding with  $\approx 55 \times 55$  km at the equator. This grid size is commonly used in global change research (Leemans & Van

den Born, 1995; Pan *et al.*, 1995). First, the type and relative area of the component soil units occurring at the centre of each  $5' \times 5'$  grid-cell of the digitized Soil Map of the World were identified and characterized, using composition rules developed by FAO (1991). Next, the information for the 36 component  $5' \times 5'$  cells of a particular  $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$  grid were computed, providing the definitive area-data. The gridding algorithms were prepared by staff of FAO's Land and Water Development Division, with whom WISE personnel cooperated closely.

#### Future developments

While the spatial resolution of the original, digital Soil Map of the World (Food and Agriculture Organization, 1991) is larger than that of the (derived)  $\frac{1}{2}^\circ$  by  $\frac{1}{2}^\circ$  WISE database (Batjes *et al.*, 1995), the complement of soil profiles held in WISE is much larger and of higher quality than the set which FAO has at its disposition. Consequently, ISRIC and FAO plan to combine both databases in the near future. In practice, this will allow the use of the WISE soil profile database linked with data on the full soil unit composition by  $5' \times 5'$  grid-cell (including information on topsoil textural class, slope class, and phases) as contained on the CD-ROM of the Soil Map of the World (Food and Agriculture Organization, 1995). In addition to this, the  $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$  spatial data set of WISE will be released also for use in global studies that require a smaller spatial resolution.

## CONCLUSIONS

This paper presents medians for selected properties of the 106 soil units of the 1:5 M scale FAO–UNESCO Soil Map

Table 3. Median values for selected soil properties by 1974 FAO-UNESCO soil unit

FAO.74	FAO UNIT	PH.T	PH.S	OC.T	OC.S	CEC.T	CEC.S	CMK.T	CMK.S	ESP.T	ESP.S	BULK	PORES	AWC	DRAIN	GRAV
A	Acrisols	4.9	4.9	1.04	0.35	8.2	6.6	1.6	1.0	1.0	1.0	1.41	47	121	W	F
Af	Ferric Acrisol	5.0	4.9	0.75	0.28	6.4	5.4	1.6	1.0	1.0	1.0	1.44	46	122	W	F
Ag	Gleyic Acrisol	4.7	4.7	1.10	0.30	9.4	11.0	1.6	1.1	1.0	1.0	1.41	47	126	I	F
Ah	Humic Acrisol	4.9	5.1	2.30	0.76	13.0	8.0	2.1	1.0	1.0	1.0	1.32	50	128	W	F
Ao	Orthic Acrisol	4.9	5.0	0.78	0.26	7.5	8.0	1.5	1.4	1.0	1.0	1.38	48	113	W	F
Ap	Plinthic Acrisol	4.7	4.8	1.04	0.31	6.2	5.1	1.3	0.7	1.0	0.0	1.53	42	112	M	F
B	Cambisols	6.1	6.4	1.05	0.38	17.6	13.8	9.3	9.0	1.0	1.0	1.36	49	130	W	F
Bc	Chromic Cambisol	6.9	7.2	1.02	0.37	20.4	16.7	20.8	25.0	0.0	1.0	1.33	50	128	W	F
Bd	Dystic Cambisol	5.1	5.2	1.94	0.40	17.6	9.8	1.9	1.0	1.0	1.0	1.27	52	132	W	F
Be	Eutric Cambisol	6.7	6.9	0.90	0.30	18.6	18.2	14.9	12.1	1.0	2.0	1.45	45	128	W	F
Bf	Ferralic Cambisol	5.1	5.3	0.95	0.29	7.3	5.3	1.6	1.4	1.0	1.0	1.28	52	130	W	F
Bg	Gleyic Cambisol	5.8	6.2	0.91	0.36	15.1	12.6	6.8	6.8	1.0	1.0	1.50	43	130	I	F
Bh	Humic Cambisol	5.1	5.3	3.04	0.76	25.8	16.8	4.3	2.0	2.0	3.0	1.15	57	137	W	F
Bk	Calcic Cambisol	8.1	8.2	0.63	0.36	20.6	18.1	46.3	46.4	2.0	2.0	1.45	45	130	W	F
Bv	Vertic Cambisol	6.9	7.4	0.84	0.43	39.2	37.9	37.8	40.5	2.0	2.0	1.41	47	130	M	F
Bx	Gelic Cambisol	5.0	5.1	1.80	1.00	20.1	13.3	5.2	5.3	0.0	0.0	1.43	46	143	I	F
C	Chernozems	7.9	8.1	1.32	0.50	22.8	19.8	28.9	27.3	1.0	2.0	1.45	45	111	M	F
Cg	Glossic Chernozem	7.7	8.1	1.32	0.50	23.0	20.0	30.0	27.0	1.0	2.0	1.45	45	111	M	F
Ch	Haplic Chernozem	7.7	7.8	1.65	0.60	22.9	17.3	23.9	20.5	1.0	2.0	1.42	46	115	W	F
Ck	Calcic Chernozem	8.1	8.2	1.04	0.40	26.4	27.1	42.1	38.9	1.0	2.0	1.37	48	110	M	F
Cl	Luvic Chernozem	7.6	8.1	0.90	0.50	20.3	13.7	26.1	29.3	2.0	4.0	1.65	38	125	I	F
D	Podzoluvisols	5.1	5.3	0.76	0.14	4.1	7.8	3.0	5.0	1.0	2.0	1.65	38	113	M	F
Dd	Dystic Podzoluvisol	4.9	5.2	1.00	0.17	5.8	10.8	3.5	8.4	6.0	4.0	1.57	41	121	I	F
De	Eutric Podzoluvisol	5.1	5.3	0.78	0.13	4.9	5.3	2.7	4.9	0.0	0.0	1.71	35	101	W	F
Dg	Gleyic Podzoluvisol	6.0	5.3	0.48	0.13	4.1	6.5	3.8	5.1	0.0	0.0	1.65	38	110	I	F
E	Rendzinas	7.6	8.1	2.00	0.58	35.9	14.7	33.8	46.8	1.0	6.0	1.34	49	39	W	A
F	Ferralsols	5.0	5.1	1.33	0.43	8.2	4.8	1.1	0.5	0.0	1.0	1.26	52	80	W	F
Fa	Acric Ferralsol	4.7	5.1	1.73	0.50	6.7	3.0	0.4	0.2	2.0	0.0	1.12	58	80	W	F
Fh	Humic Ferralsol	4.9	5.1	2.27	0.98	9.6	6.7	1.5	1.1	1.0	1.0	1.21	54	88	W	F
Fo	Orthic Ferralsol	5.0	5.2	1.12	0.37	8.9	4.7	1.2	0.5	0.0	0.0	1.40	47	80	W	F
Fp	Plinthic Ferralsol	4.9	5.4	1.29	0.51	6.8	4.0	2.1	1.1	0.0	2.0	1.31	51	81	W	F
Fr	Rhodic Ferralsol	5.5	5.5	1.19	0.40	9.1	6.0	2.9	2.2	1.0	1.0	1.25	53	80	W	F
Fx	Xanthic Ferralsol	4.5	4.8	1.00	0.34	5.9	3.6	0.5	0.3	0.0	0.0	1.26	52	80	W	F
G	Gleysols	5.7	6.3	1.51	0.32	20.6	15.4	17.3	14.0	1.0	2.0	1.38	48	122	W	F
Gc	Calcic Gleysol	7.5	8.4	0.78	0.10	33.3	16.3	36.2	38.3	2.0	8.0	1.65	38	128	I	F
Gd	Dystic Gleysol	5.0	5.0	1.50	0.34	16.4	71.0	6.8	4.7	1.0	1.0	1.20	55	118	P	F
Ge	Eutric Gleysol	6.2	6.7	1.19	0.30	20.4	17.9	17.6	15.9	2.0	2.0	1.43	46	122	P	F
Gh	Humic Gleysol	5.1	5.2	3.04	0.60	15.0	9.0	1.9	1.0	1.0	1.0	1.45	45	125	P	F
Gm	Mollic Gleysol	6.6	7.2	2.20	0.36	33.5	21.4	26.8	18.3	1.0	2.0	1.44	46	127	P	F
Gp	Plinthic Gleysol	5.4	5.1	2.58	0.33	20.6	6.0	3.0	0.6	1.0	0.0	1.03	61	135	I	F
Gx	Gelic Gleysol	5.7	7.0	2.15	0.97	19.1	13.9	17.6	16.2	2.0	2.0	1.43	46	104	P	F



H	Phaeozems	6.4	7.0	1.60	0.52	22.8	24.4	20.4	23.9	1.0	2.0	1.46	45	122	W	C
Hc	Calcic Phaeozem	7.9	8.2	1.36	0.48	30.0	198	50.5	48.1	1.0	2.0	1.49	44	120	W	C
Hg	Gleyic Phaeozem	6.0	6.9	1.42	0.38	24.1	220	196	199	2.0	4.0	1.45	45	121	I	C
Hh	Haplic Phaeozem	6.4	6.7	1.76	0.50	24.2	23.2	209	21.4	1.0	1.0	1.43	46	120	W	C
Hi	Luvic Phaeozem	6.3	6.9	1.60	0.62	21.6	26.1	188	23.9	1.0	2.0	1.48	44	123	W	C
I	Lithosols	7.7	-	1.80	-	12.3	-	39.3	-	2.0	-	1.42	46	13	S	M
J	Fluvisols	7.5	7.8	0.70	0.40	14.8	14.3	11.2	13.0	2.0	2.0	1.40	47	116	M	F
Jc	Calcic Fluvisol	8.1	8.1	0.48	0.34	11.8	11.7	294	23.3	2.0	2.0	1.45	45	110	M	F
Jd	Dystic Fluvisol	4.8	5.0	1.59	0.40	11.9	6.8	3.7	3.5	1.0	2.0	1.36	49	124	P	F
Je	Eutric Fluvisol	7.0	7.5	0.78	0.42	16.8	17.2	11.3	15.0	2.0	2.0	1.42	46	119	M	F
Jt	Thionic Fluvisol	4.8	3.8	2.51	2.20	18.3	23.6	12.3	12.8	18.0	13.0	1.07	60	130	P	F
K	Kastanozems	7.5	8.0	1.22	0.50	20.3	24.3	199	31.0	2.0	3.0	1.55	42	116	W	F
Kh	Haplic Kastanozem	7.4	7.7	1.30	0.47	19.6	31.0	199	33.7	1.0	3.0	1.79	32	116	W	F
Kk	Calcic Kastanozem	7.9	8.3	1.13	0.52	21.8	24.1	33.2	28.5	1.0	3.0	1.41	47	98	W	F
Kl	Luvic Kastanozem	5.9	7.4	0.96	0.27	13.3	21.0	6.2	18.7	3.0	9.0	1.55	42	130	W	F
L	Luvic Luvisols	6.4	6.7	0.56	0.28	10.5	11.6	94	11.6	1.0	2.0	1.54	42	89	M	F
La	Albic Luvisol	6.4	7.1	0.58	0.20	9.5	6.5	6.6	7.9	0.0	3.0	1.62	39	102	M	F
Lc	Chromic Luvisol	6.4	6.5	0.72	0.36	13.0	14.9	10.3	14.4	1.0	1.0	1.53	42	89	W	F
Lf	Ferric Luvisol	5.9	5.8	0.47	0.26	5.5	5.8	4.5	4.0	2.0	2.0	1.55	42	82	W	F
Lg	Gleyic Luvisol	6.1	6.5	0.64	0.20	15.6	16.4	14.1	16.1	2.0	2.0	1.48	44	95	I	F
Lk	Calcic Luvisol	8.0	8.3	0.40	0.23	8.0	10.6	12.2	25.6	3.0	3.0	1.57	41	90	M	F
Lo	Orthic Luvisol	6.3	6.7	0.63	0.26	11.5	13.0	10.1	12.0	1.0	1.0	1.55	42	91	M	F
Lp	Plinthic Luvisol	5.8	6.0	0.46	0.31	4.3	6.0	3.1	4.8	1.0	1.0	1.66	37	80	M	F
Lv	Vertic Luvisol	7.0	7.0	1.06	0.59	25.5	28.1	23.2	25.2	1.0	2.0	1.50	43	89	W	F
M	Greyzems	6.7	8.1	1.32	0.27	20.6	14.5	18.5	13.4	2.0	8.0	1.50	43	113	W	F
Mg	Gleyic Greyzem	6.7	6.2	2.26	1.25	20.6	28.3	26.0	21.9	2.0	2.0	1.50	43	110	P	F
Mo	Orthic Greyzem	6.7	8.1	1.31	0.24	20.6	10.9	18.3	10.3	2.0	9.0	1.50	43	115	W	F
N	Nitrosols	5.6	5.6	0.88	0.40	11.5	10.6	5.0	7.2	1.0	1.0	1.43	46	75	W	F
Nd	Dystic Nitrosol	4.9	5.0	0.87	0.30	7.9	8.6	1.7	1.3	1.0	1.0	1.42	46	70	W	F
Ne	Eutric Nitrosol	6.2	6.4	0.60	0.36	11.0	11.9	7.6	9.7	1.0	1.0	1.49	44	75	W	F
Nh	Humic Nitrosol	5.2	5.3	2.49	0.70	19.4	17.9	2.0	3.8	1.0	2.0	1.27	52	85	W	F
O	Histosols	4.7	4.8	38.60	41.00	80.2	90.4	35.2	49.9	1.0	1.0	0.31	88	480	V	F
Od	Dystic Histosol	4.5	4.5	35.00	37.40	75.5	84.4	22.1	27.8	1.0	1.0	0.31	88	480	V	F
Oe	Eutric Histosol	5.8	5.8	40.33	44.46	86.4	100.0	74.0	99.1	1.0	1.0	0.33	88	480	V	F
Ox	Gelic Histosol	3.9	5.3	45.60	37.80	73.4	128.0	35.6	68.6	2.0	0.0	0.31	88	480	P	F
P	Podzols	4.4	4.9	2.92	0.51	15.9	4.4	0.6	0.2	0.0	0.0	1.32	50	94	W	F
Pf	Ferric Podzol	3.8	5.3	7.87	0.89	15.9	8.6	2.1	1.1	0.0	0.0	1.32	50	105	W	F
Pg	Gleyic Podzol	4.7	4.8	2.45	0.72	13.0	4.9	0.5	0.2	1.0	0.0	1.28	52	102	I	F
Ph	Humic Podzol	4.2	4.8	1.94	0.40	6.5	2.0	0.3	0.2	0.0	1.0	1.35	49	82	W	F
Pl	Leptic Podzol	4.9	5.4	2.53	0.23	11.8	1.3	5.9	0.0	0.0	0.0	1.36	49	127	W	F
Po	Orthic Podzol	4.3	5.0	3.15	0.55	20.6	8.8	0.7	0.3	0.0	0.0	1.33	50	93	W	F
Pp	Placic Podzol	4.2	5.0	6.67	1.30	25.8	7.7	0.4	0.1	1.0	0.0	1.27	52	114	I	F
Q	Arenosols	6.3	6.3	0.20	0.10	3.2	2.6	2.6	2.2	3.0	4.0	1.61	39	42	S	F
Qa	Albic Arenosol	6.1	5.6	0.30	0.10	2.7	1.5	1.7	0.8	1.0	0.0	1.59	40	45	W	F
Qc	Cambic Arenosol	6.6	6.9	0.20	0.10	3.3	3.1	3.6	4.2	3.0	0.0	1.62	39	42	W	F
Qf	Ferralic Arenosol	5.6	5.4	0.26	0.10	2.9	2.2	1.6	1.0	3.0	3.0	1.63	38	57	S	F
Ql	Luvic Arenosol	6.5	6.2	0.20	0.10	3.4	3.2	2.6	2.2	3.0	3.0	1.58	40	40	S	F
R	Regosols	6.3	6.4	0.66	0.18	10.2	6.4	5.4	3.3	2.0	2.0	1.51	45	100	W	M
Rc	Calcic Regosol	8.0	8.2	0.40	0.43	17.9	13.7	47.5	39.6	2.0	2.0	1.46	45	117	W	M
Rd	Dystic Regosol	5.1	5.4	0.88	0.20	8.0	4.8	0.9	0.8	1.0	1.0	1.51	43	94	W	M
Re	Eutric Regosol	6.4	6.7	0.60	0.15	10.0	6.0	6.9	4.8	2.0	4.0	1.56	41	94	W	M
Rx	Gelic Regosol	5.6	6.2	3.75	2.55	59.8	10.3	7.7	6.7	0.0	0.0	1.51	43	160	M	M

(Continued)

Table 3. (Continued)

FAO_74	FAO UNIT	PH.L	PH.S	OC.T	OC.S	CEC.T	CEC.S	CMK.T	CMK.S	ESP.T	ESP.S	BULK	PORES	AWC	DRAIN	GRAV
S	Solonetz	8.2	8.7	0.49	0.20	15.2	17.7	20.4	31.7	17.0	55.0	1.64	38	115	I	F
Sg	Gleyic Solonetz	8.0	8.8	0.67	0.17	15.1	24.5	14.8	13.6	10.0	45.0	1.72	35	119	P	F
Sm	Mollic Solonetz	6.6	8.4	1.25	0.23	18.2	16.6	13.5	25.4	24.0	125.0	1.68	37	130	I	F
So	Orthic Solonetz	8.4	8.8	0.37	0.20	13.8	16.4	29.6	37.9	17.0	53.0	1.63	38	113	I	F
T	Andosols	5.8	6.0	4.80	1.95	26.5	20.9	5.5	5.3	1.0	1.0	0.73	72	187	W	F
Th	Humic Andosol	5.5	5.9	6.00	2.28	27.4	22.0	3.9	3.4	1.0	1.0	0.70	74	188	W	F
Tm	Mollic Andosol	6.1	6.3	3.90	1.71	27.2	20.6	14.5	14.3	1.0	2.0	0.73	72	182	W	F
Tb	Ochric Andosol	5.8	6.3	5.48	1.48	27.2	34.2	6.2	24.3	2.0	2.0	0.79	70	135	W	F
Tv	Vitric Andosol	6.1	6.2	2.79	1.30	19.0	14.1	5.7	6.8	1.0	1.0	0.80	70	190	W	F
U	Rankers	5.6	4.8	2.70	2.88	12.8	6.7	2.8	0.4	0.0	2.0	1.48	44	36	W	M
V	Vertisols	7.5	8.0	0.80	0.50	45.3	47.9	48.7	53.3	2.0	4.0	1.67	37	130	I	F
Vc	Chromic Vertisol	7.9	8.1	0.70	0.46	46.1	46.1	52.1	60.3	2.0	4.0	1.71	35	130	M	F
Vp	Pellic Vertisol	7.2	7.8	0.92	0.60	45.3	50.7	45.8	51.3	2.0	4.0	1.59	40	130	I	F
W	Planosols	6.0	6.6	0.65	0.27	8.6	14.8	5.9	12.2	3.0	5.0	1.57	41	100	I	F
Wd	Dystic Planosol	4.2	4.6	1.10	0.30	16.5	16.2	0.8	1.6	1.0	1.0	1.28	52	101	P	F
We	Eutric Planosol	5.9	6.4	0.50	0.20	4.1	12.9	4.0	12.9	3.0	3.0	1.51	43	91	I	F
Wh	Humic Planosol	6.0	7.0	0.50	0.20	15.4	16.3	14.4	17.1	1.0	1.0	1.62	39	89	V	F
Wm	Mollic Planosol	6.0	7.6	1.58	0.40	17.1	28.0	13.6	25.8	2.0	5.0	1.42	46	112	I	F
Ws	Solodic Planosol	6.4	7.8	0.49	0.27	6.6	12.8	5.3	11.7	7.0	15.0	1.72	35	100	I	F
Wx	Gelic Planosol	6.0	7.0	0.65	0.27	8.6	14.8	5.9	1.6	3.0	5.0	1.57	41	100	I	F
X	Xerosols	7.6	7.8	0.42	0.20	10.2	11.4	15.2	29.1	2.0	3.0	1.49	44	110	W	F
Xh	Haplic Xerosol	8.0	8.0	0.59	0.29	23.5	19.7	29.7	48.3	6.0	14.0	1.52	43	110	W	F
Xk	Calcic Xerosol	7.9	8.3	0.70	0.28	12.5	9.7	44.3	49.2	3.0	23.0	1.43	46	108	W	F
Xl	Luvic Xerosol	7.3	7.8	0.38	0.20	7.9	10.7	9.3	19.3	2.0	2.0	1.53	42	95	W	F
Xy	Gypsic Xerosol	7.9	7.8	0.73	0.20	18.8	11.0	54.6	47.4	9.0	39.0	1.39	48	108	W	F
Y	Yermosols	7.9	8.0	0.25	0.17	7.5	8.1	10.0	23.7	3.0	4.0	1.51	43	99	W	C
Yh	Haplic Yermosol	8.1	8.2	0.23	0.14	5.5	6.5	11.6	28.9	7.0	9.0	1.54	42	105	W	C
Yk	Calcic Yermosol	8.0	8.1	0.28	0.14	12.6	10.4	6.3	22.3	7.0	8.0	1.49	44	105	W	C
Yl	Luvic Yermosol	7.5	7.9	0.30	0.20	6.4	7.8	8.2	41.1	2.0	3.0	1.60	40	93	W	C
Yt	Takyric Yermosol	7.2	6.9	0.21	0.17	7.5	8.1	10.0	23.7	3.0	4.0	1.51	43	99	P	C
Yy	Gypsic Yermosol	7.8	7.8	0.18	0.14	13.0	7.9	20.1	3.8	1.0	1.0	1.18	55	100	W	C
Z	Solonchaks	8.2	8.3	0.43	0.20	13.2	15.0	39.6	41.0	43.0	101.0	1.48	44	135	I	F
Zg	Gleyic Solonchak	8.3	8.5	0.50	0.20	17.4	15.1	39.2	25.2	113.0	56.0	1.47	45	138	P	F
Zm	Mollic Solonchak	7.8	8.1	1.33	0.47	37.0	35.2	45.8	78.7	34.0	73.0	1.27	52	189	P	F
Zo	Orthic Solonchak	8.1	8.2	0.36	0.18	11.3	14.4	40.0	43.6	28.0	111.0	1.49	44	134	M	F
Zt	Takyric Solonchak	7.7	7.8	0.69	0.55	0.0	0.0	39.6	41.0	43.0	101.0	1.48	44	100	I	F

The abbreviation \_T refers to topsoil (0–30 cm) and \_S to the subsoil (30–100 cm), except for Lithosols (0–10 cm).

FAO\_74: symbol for soil unit in FAO–UNESCO (1974) legend.

FAO unit: name for above.

PH: median soil pH, measured in water.

OC: median organic carbon (%).

CEC: median cation exchange capacity (cmolc/kg; 1 M NH<sub>4</sub>OAc at pH 7).

CMK: median of sum of exchangeable Ca, Mg and K (cmolc/kg).

ESP: median exchangeable sodium percentage (% of CEC).

BULK: median bulk density (g/cm<sup>3</sup>).

PORES: median total porosity (%).

AWC: available water capacity in mm to a depth of 100 cm (or less if soil depth is shallower), for range pH 2.5 to pH 4.2 (33 to 1500 KPa).

DRAIN: drainage class (see text); V = Very poorly drained; P = Poorly drained; I = Imperfectly drained; M = Moderately well drained; W = Well drained; S = Somewhat excessively drained; E = Excessively drained (see FAO, 1991).

GRAV: median content of fragments > 2 mm (see text); F: Few, 0%–5%; C: Common, 6%–15%; M: Many, 16%–40%; A: Abundant, > 41% by volume.

Medians for soil pH and AWC are taken from Batjes (1995a, 1996), respectively.

of the World. While comprehensive studies have already been prepared for some of the attributes considered, notably soil pH and available water capacity (Batjes 1995a, 1996), the values presented for the other attributes remain of a preliminary nature. Thus the dataset should only be used for studies at the global level; users are cautioned against using the ability of modern GIS to increase the 'resolution' of the Soil Map of the World beyond its published scale of 1:5 M. Studies at the continental and regional level must be based on comprehensive sets of regionally representative soil profiles and updated information on the geographic distribution of soils in the considered regions (Oldeman & Van Engelen, 1993; Le Bas & Jamagne, 1996). A data file with 1125 profiles derived from WISE is available in the public domain (Batjes, 1995b). This subset, with its technical documentation, formed an ISRIC contribution to the activities of the Global Soils Data Task Group of IGBP-DIS (Scholes *et al.*, 1995) also intended for global change modelling.

Soil science has long recognised the strong links between soil and terrain, a relationship that can be expressed through the compilation of physiographically based soil maps. In using physiographically defined map units, as opposed to essentially taxonomically defined soil mapping units, a better geographical basis will be provided for studies of global change than has been the case so far with the Soil Map of the World. ISRIC, FAO, UNEP and ISSS are in the process of updating the information on the world soil resources in SOTER, the World Soil and Terrain Database programme (Oldeman & Van Engelen, 1993; Van Engelen & Wen, 1995), which is to supersede the current Soil Map of the World (Food and Agriculture Organization, 1995) upon its completion. Meanwhile, ISRIC and FAO are planning to combine the best elements of their respective soil databases on a CD-ROM which is to be presented as a unified product to the global modelling community in the near future.

## ACKNOWLEDGEMENTS

The WISE database was developed at ISRIC with initial sponsorship from the Netherlands National Research Programme on Global Air Pollution and Climate Change (Project 851039). As with any collaborative activity, the work has been carried out with the help of many people. The contributions of staff members of the USDA Soil Conservation Service (NRCS), Food and Agriculture Organization (FAO), International Soil Reference and Information Centre (ISRIC), and a wide range of national soil survey organizations in providing representative soil profiles for the WISE database are gratefully acknowledged. I specially thank Dr E.M. Bridges (ISRIC) and Dr F.O. Nachtergaele (FAO) for their contributions. Constructive comments by Dr R. Brinkman (FAO) on an earlier version are acknowledged.

## REFERENCES

- ARNOLD, R.W. 1995. Role of soil survey in obtaining a global carbon budget. In: *Soils and Global Change* (eds R. Lal, J. Kimble, E. Levine & B.A. Stewart), Lewis Publishers, Boca Raton, pp. 257–263.
- BACHELET, D. & NEUE, H.U. 1993. Methane emission from wetland rice areas. *Chemosphere* 6, 19–37.
- BATJES, N.H. & BRIDGES, E.M. 1994. Potential emissions of radiatively active gases from soil to atmosphere with special reference to methane: development of a global database (WISE). *Journal of Geophysical Research* 99(D8), 16,479–16,489.
- BATJES, N.H. 1995a. *A global data set of soil pH properties*. Technical Paper 27, International Soil Reference and Information Centre, Wageningen.
- BATJES, N.H. 1995b. *A homogenized soil data file for global environmental research: A subset of FAO, ISRIC and NRCS profiles (Version 1.0)*. Working Paper and Preprint 95/10, International Soil Reference and Information Centre, Wageningen.
- BATJES, N.H. 1996. Development of a world data set of soil water retention properties using pedotransfer rules. *Geoderma* 71, 31–52.
- BATJES, N.H., BRIDGES, E.M. & NACHTERGAELE, F.O. 1995. World Inventory of Soil Emission Potentials: development of a global soil database of process controlling factors. In: *Climate Change and Rice* (eds S. Peng *et al.*), Springer-Verlag, Heidelberg, pp. 110–115.
- BOUWMAN, A.F., FUNG, I., MATTHEWS, E. & JOHN, J. 1993. Global analysis of the potential for N<sub>2</sub>O production in natural soils. *Global Biogeochemical Cycles* 7, 557–597.
- CHADWICK, M.J. & KUYLENSTIERNA, J.C.I. 1990. *The relative sensitivity of ecosystems in Europe to acidic depositions*. Stockholm Environment Institute & University of York, York.
- FOOD AND AGRICULTURE ORGANIZATION, 1974. *FAO–UNESCO Soil Map of the World: Vol. 1, Legend*. UNESCO, Paris.
- FOOD AND AGRICULTURE ORGANIZATION, 1990. *Guidelines for soil description* (3rd revised ed.). FAO & ISRIC, Rome.
- FOOD AND AGRICULTURE ORGANIZATION, 1991. *Digitized Soil Map of the World*. World Soil Resources Report 67, FAO, Rome.
- FOOD AND AGRICULTURE ORGANIZATION, 1995. *Digital Soil Map of the World and Derived Soil Properties (version 3.5)*. CD-ROM, FAO, Rome.
- HAGEN, N., KLEEGERG, H.B. & NIEKAMP, O. 1993. Parameter estimation for ecosystem models with special regard to target functions. *Modelling Geobiosphere Processes* 2, 293–325.
- LE BAS, C. & JAMAGNE, N. 1996. *Soil Databases to Support Sustainable Development*. Report EU16371, Joint Research Centre of the European Commission and INRA-SESCPF, Orleans.
- LEEMANS, R. & VAN DEN BORN, G.J. 1995. Determining the potential distribution of vegetation, crops and agricultural productivity. *Water, Air, and Soil Pollution* 76, 133–161.
- LUYTEN, J.C. 1995. *Sustainable world food production and environment*. Report 37, Research Institute for Agrobiology and Soil Fertility (AB–BLO), Wageningen.
- MADSEN, H.B. & JONES, R.J.A. 1995. The establishment of a soil profile analytical database for the European Union. In: *European Land Information Systems for Agro–Environmental Monitoring* (eds D. King, R.J.A. Jones & A.J. Thomasson), pp. 55–63. Office for Official Publications of the European Communities, Luxembourg.
- NEAVE, P., KIRKWOOD, V. & DUMANSKI, J. 1995. *Review and assessment of available indicators for evaluating sustainable land management*. Technical Bulletin 1995–72, Centre for Land and Biological Resources Research, Agriculture and Agri–Food Canada, Ottawa.
- NELSON, D.W. & SOMMERS, L.E. 1982. Total carbon, organic carbon, and organic matter. In: *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* (2nd edition) (eds A.L. Page, R.H. Miller & D.R. Keeney), pp. 539–580. Agronomy Series No. 9, American Society of Agronomy, Inc. Madison, Wisconsin.
- OLDEMAN, L.R. & VAN ENGELN, V.W.P. 1993. A World Soils and Terrain Digital Database (SOTER) An improved assessment of land resources. *Geoderma* 60, 309–35.
- PAN, Y., MCGUIRE, A.D., KICKLIGHTER, D.W. & MELILLO, J.M. 1995. The importance of climate and soils for estimates of net primary production: a sensitivity analysis with the terrestrial ecosystem model. *Global Change Biology* 2, 5–23.
- PRENTICE, I.C., CRAMER, W., HARRISON, S.P., LEEMANS, R., MONSERUD, R.A. & SOLOMON, A.M. 1992. A global biome model based on plant physiology and dominance, soil properties and climate. *Journal of Biogeography* 19, 117–134.
- SCHOLES, B., SKOLE, R.J.D. & INGRAM, J.S. 1995. *A global database of soil properties: proposal for implementation*. IGBP-DIS Working Paper 10, International Geosphere Biosphere Program, Data and Information System, Paris.
- SOIL SURVEY STAFF 1993. *Soil Survey Manual (revised edition)*. United States Department of Agriculture Handbook No. 18, USDA, Washington.
- STATISTIX 1994. *User's Manual (version 4.1)*. Analytical Software, Tallahassee.
- VAN ENGELN, V.W.P. & WEN, T.T. 1995. *Global and national soils and terrain digital databases (SOTER): Procedures manual (revised edition)*. FAO–ISRIC–

- ISSS-UNEP, International Soil Reference and Information Centre, Wageningen. [First edition also issued by FAO as World Soil Resources Report 74].
- VAN REEUWIJK, L.P. 1993. Procedures for soil analysis. Technical Paper 9, ISRIC, Wageningen, pp. 18/1-18/6.
- WEBB, S.R., ROSENZWEIG, C.E. & LEVINE, E.R. 1991. *A global data set of soil particle size properties*. NASA Technical Memorandum 4286, New York.
- WESSMAN, C.A. 1992. Spatial scales and global change: bridging the gap from plots to GCM grid cells. *Annual Review of Ecological Systems* 23, 175-200.
- ZOBLER, L. 1986. *A world soil file for global climate modelling*. NASA Technical Memorandum 87802, New York.
- ZUIDEMA, G., VAN DEN BORN, G.J., ALCAMO, J. & KREILEMAN, G.J.J. 1995. Simulation of global land cover changes as affected by economic factors and climate. *Water, Air and Soil Pollution* 76, 163-198.

© British Society of Soil Science

**First Announcement**

**Fifth Symposium on the  
Biogeochemistry of Wetlands**

*September 16th to 19th, 1997  
Royal Holloway University of London, UK*

**Suggestions for papers on the following topics are invited:**

- Functional assessment of wetland ecosystems
- Nutrient cycling in saltmarshes
- Plant-soil interactions of wetlands
- Modelling of wetland biogeochemical processes
- Toxic chemicals in wetlands
- European wetlands
- Tropical wetland ecosystems
- Water quality
- Freshwater biogeochemistry
- The effects of climate change on wetlands
- The role of wetlands in global nutrient cycles
- Carbon dynamics
- Land-use and wetland conflicts
- Wetland biodiversity

**For further information please contact:**  
5th Symposium on the Biogeochemistry of Wetlands,  
Royal Holloway Institute for Environmental Research,  
Royal Holloway University of London,  
Huntersdale,  
Callow Hill, Virginia Water,  
GU25 4LN, UK  
Tel +44 (0) 1784 477 404  
Fax +44 (0) 1784 477 427  
EMail: rhier@rhbnc.ac.uk