Technical Paper 27

A GLOBAL DATA SET OF SOIL pH PROPERTIES

N. H. Batjes

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

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Abstract

A standardized global data set of soil pH(H_2O) properties is presented. It has been compiled using the digital database developed for the "World Inventory of Soil Emission Potentials" (WISE) project. Median pH(H_2O) and extremes have been computed for both the topsoil (0-30 cm) and subsoil (30-100 cm) of all the 106 second level soil units considered in the original version of the FAO legend. The study is based on the 4,353 soil profiles currently held in the WISE profile database, corresponding with a total of 20,995 horizons. Only those horizons for which the pH(H_2O) has been measured in a 1:1 to 1:5 soil:water suspension have been used in this study, corresponding with a total of 19,229 samples. Decision-rules have been developed to provide surrogate data for the still under-represented soil units. Results of the pH analyses have been used to generate a global ½° by ½° database of soil pH using taxo-transfer functions. Global data sets of soil pH are presented for both the topsoil and subsoil, and a broad interpretation of soil pH for agricultural and environmental applications is given. The data sets can be used to refine "soil reduction" factors in global environmental models.

Keywords: Soil Digital Database; Soil reaction (pH)

1. Introduction

Soil pH is a useful attribute, in that whether a soil is acidic, neutral or alkaline influences the solubility of various compounds, the relative bonding of ions to exchange sites, and the activity of various microorganisms (McLean, 1973). This report presents the methodology that has been developed to compile a global data set of soil pH(H_2O) using the soil database which has been developed at ISRIC during tenure of a project entitled "World Inventory of Soil Emission Potentials", with the acronym WISE (Batjes and Bridges, 1994). The integrated WISE database consists of two parts, a spatial component and an attribute data component. The attribute data consist of soil profiles considered to be representative for the various soil units shown on a ½° latitude by ½° longitude grid-map, which has been derived from FAO's edited digital Soil Map of the World (FAO, 1991). Up to a maximum number of ten main soil units are considered for each grid cell. The properties of the component soil units of each grid can be characterized using appropriate data selected from the WISE profile database. The resulting, geo-referenced sets of derived soil data can be linked to a raster-GIS, for subsequent use in global environmental studies (Batjes *et al.*, 1995).

Section 2 discusses the procedures and assumptions, and aspects of data set compilation are discussed in Section 3. Results are discussed on a soil unit basis in Section 4.1, and an agricultural and environmental interpretation is given in Section 4.2. Possibilities for further work are outlined in Section 5. A full characterization of pH(H_2O) ranges, per FAO-Unesco soil unit, is given in the Appendix.

2. Procedures and materials

2.1 Soil reaction

Soil reaction or pH is defined as the negative logarithm of the hydrogen ion concentration in solution. It is determined largely by soil composition, cation exchange processes, and hydrolysis reactions associated with the various organic and inorganic soil components (Thomas and Hargrove, 1984), as well as by the CO_2 concentration in the soil gaseous and liquid phase. In the soil, a distinction can be made between actual acidity, which is the H^+ concentration of the soil solution, and potential acidity, which also includes H^+ ions adsorbed to soil colloids. Besides the actual soil fertility, the buffer capacity of a soil is of importance in determining the pH in that hydrogen ions produced by various processes in the soil are buffered by soil colloids.

The actual acidity of a soil is readily determined by measuring the pH of the soil solution. Soil pH values can change over relatively short time scales as a result of seasonal climate, land management practices, and environmental pollution. Localized effects of fertilizers may give sizeable pH variations within the space of a few metres. Redox processes caused by alternating aerobic and anaerobic conditions may give rise to strongly acidic or alkaline soils and waters (Van Breemen, 1987). Marked decreases in pH may occur upon the oxidation of pyrite present in poorly drained acid sulphate soils. Acid precipitation can strongly affect those agricultural soils where liming is minimal, particularly when the soil's buffering capacity is low. Anthropogenic acidification of soils often leads to further environmental and health hazards, particularly in poorly buffered systems, because of the increased mobility of potentially toxic heavy metals at low pH values (Stigliani, 1991).

The soil pH is an intensity factor, and factors affecting pH values measured have been discussed by McLean (1973). Effects of dilution on soil pH have been discussed extensively elsewhere (Landon, 1991 p. 113), and that review indicates that pH values in water increase with the dilution of the suspension. This increase is particularly noted, when pH values obtained in a saturated paste are compared with those obtained for more diluted suspensions. Thomas and Hargrove (1984) state that differences of several tenths of a pH unit are observed in going from a 1:10 to 1:1 soil:water mixture. Similarly, experience of the ISRIC laboratory shows that pH(H_2O) determined in 1:1 to 1:5 solutions only differ by some tenths of a pH-unit. Also Krüpskiï *et al.* (1969), Schachtschabel (1971) and Landon (1991) found that the values of pH measured in a 1:2.5 soil:water solution deviate only slightly from those obtained by making use of a dilution ration of 1:1 to 1:5 (see also Vogel, 1994). The pH values for 1:5 soil:water suspensions may be 0.5 to 1.5 units higher than those for corresponding saturated pastes (Dewis *et al.*, 1970). The random analytical error in pH measurement is in the order of 0.2 units (Landon, 1991, p. 110; Van Reeuwijk, *pers. comm.*, 1994). Consequently, only routine soil pH measurements made on extracts from soil suspensions which vary from 1:1 to 1:5 soil:water have been considered in this study (Table 1).

Table 1. Analytical methods used for determining pH(H_2O).

Code	Analytical method
pH01	pH in 1:1 soil/water solution
pH02	pH 1:2.5 soil/water solution
pH03	pH 1:5 soil/water solution
pH04	pH in 1:2 soil/water solution
pH05	pH in water saturated extract*

* Not considered in this study

2.2 Selection of pH classes

Most soils have a pH(H_2O) in the range of 2.0 to 11.0, while soils with sulphuric materials may have a pH below 2.0 upon oxidation (Soil Survey Staff, 1993). Four soil pH ranges are particularly informative:

(a) a pH less than 4 indicates the presence of free acids, generally from oxidation of sulphides;

(b) a pH below 5.5 points to the likely occurrence of exchangeable Al^{3+}. Below a pH of 4.5 a significant amount of exchangeable H^+ is probably present in addition to exchangeable Al^{3+}.

(c) a pH from 7.3 to 8.5 indicates the presence of $CaCO_3$; the presence of strong concentrations of neutral soluble salts, such as NaCl and Na_2SO_4, in a saturated extract is reflected by a high electrical conductivity (EC_e > 4 dS m^{-1}).

(d) a pH greater than 8.5 indicates the presence of significant amounts of exchangeable sodium as a result of the presence of sodium carbonate (Na_2CO_3); the electrical conductivity is generally low (EC_e < 4 dS m^{-1}).

For this study, 5 broad pH classes have been considered as shown in Table 2. These ranges have been aggregated from the pH ranges considered by Soil Survey Staff (1993).

Table 2. Characterization of broad pH(H_2O) classes.

pH(H_2O)	Description
pH ≤ 4.0	Extremely acid
4.0 < pH ≤ 5.5	Very strongly and strongly acid
5.5 <pH ≤ 7.3	Moderately acid, slightly acid and neutral
7.3 <pH ≤ 8.5	Slightly and moderately alkaline
8.5 ≤ pH	Strongly and very strongly alkaline

2.3 Selection of depth ranges

All available soil samples, for which pH was measured according to the methods identified in section 2.1, were grouped according to: (a) the FAO-Unesco (1974) legend, and (b) the depth range in which they occur.

For the sake of this global study, only two broad soil depth ranges have been defined. The first, called "topsoil", refers to the uppermost part of the profile and the second, termed "subsoil", to the lowermost part, as further specified below.

In the WISE database each sample is characterized by its upper and lower boundary, called "topdep" and "botdep" respectively: (a) *topsoil*: 0 cm≤ topdep < 30 cm, and botdep < 50 cm, and (b) *subsoil*: 30 cm ≤ topdep < 100 cm, and botdep <100 cm.

2.4 Problems of missing data

The current release of the WISE database holds 4,353 profiles with 20,995 horizons, 19,229 of which have suitable pH(H_2O) data. While the pH characteristics for most soil units can be described using at least 5 profiles, this is not always the case. In situations where only a limited number of profiles was available, eventual data gaps have been filled using the following "decision rules":

(1) If there are no pH data at all for the considered depth layer (topsoil or subsoil) and first level soil unit, the median pH-value computed for all the other first level soil units, except the organic soils (Histosols) and volcanic ash soils (Andosols), has been substituted in the database. Where this has been the case, this is clearly shown (see Appendix).

(2) If there are no pH data at all for the considered depth layer (topsoil, respectively subsoil) and second level soil unit, but data are available for the other second level soil units of this first level unit, the median is replaced with the median pH(H_2O) value for these second level soil units (see Appendix).

(3) The above rules do not apply for the Histosols (O) and Andosols (T), for which the median pH(H_2O) values are computed directly.

The number of samples considered in the statistical calculations is shown in the Appendix. In computing the medians for pH(H_2O) values per soil unit, ^{10}log transformations have been applied as appropriate. In general, the confidence in the data presented will increase with the number of observations. The current findings can be updated when additional profile data for soil units, still under-represented in the WISE database, have been obtained.

3. Data set compilation

Based on the preceding criteria and associated software modules, a global data set of median pH(H_2O) values has been prepared using the WISE database linked to GIS. The legend used in the derived GIS files takes into account:

(a) the soil layer under consideration (topsoil and subsoil, respectively);

(b) the selected pH(H_2O) ranges (see Table 2); and

(c) the percentage of occurrence of soils with the given pH(H_2O) range in a given ½° by ½° grid cell.

In computing the percentage of soil units with a particular pH(H_2O) range in a grid cell, it has been necessary to account for the "miscellaneous" units considered on the Soil Map of the World (FAO, 1991). To this avail, the following "decision rules" have been introduced:

(a) Salt flats (ST) have been assigned a pH of 9.0 by default, keeping in mind their saline and sodic nature.

(b) Areas of "rock debris and desert detritus" (RK) can occur in association with soil units showing a broad range in pH, depending, amongst others on the nature of the parent material and weathering stage. The median pH(H_2O) has been set at 6.5, by default.

(c) Areas of "dune sands and shifting sands" mainly occur in desert areas, such as the Sahara. It has been assumed that these materials are slightly alkaline, resulting in an assumed median pH(H_2O) of 7.5.

(d) Some areas of the Soil Map of the World have been coded as being "not determined", for example some soils around Lake Chad. The assumption is that the median pH(H_2O) for these units is 6.5.

Inherently, the choice of class boundaries for the relative occurrence of a particular pH(H_2O) range in a grid cell will be subjective. Several tests have been carried out to identify a suitable legend before the final classes were adopted. Both "oceans" and "glaciers" have been mapped as separate categories in the GIS file. In case one particular pH-range predominates (> 60% of grid), "single" pH-units have been used. Where this was not the case, a "pH-complex" was defined.

The initial, statistical analyses of the pH data in WISE have been performed under dBASE IV, the output of which was sent to a raster GIS (IDRISI, 1993). The pH- raster GIS files (see: Batjes, 1996) follow the format adopted for the Global Ecosystem Database (Kineman, 1992).

4. Discussion

4.1 Characterization of pH per soil unit

The Soil Map of the World consists of 26 major soil units, differentiated at the highest level on the basis of effects of different soil forming processes in so far these are reflected in observable and measurable properties (FAO-Unesco, 1974). Soil pH values are not considered explicitly in the Legend, but some "terms" reflect the overall pH class (e.g., thionic, dystric, humic, eutric, mollic, calcaric, calcic, and solodic, listed in the general sequence from acid to alkaline). Nonetheless, general trends can be observed from the present study in which the number of samples available per sub-unit and depth layer, computed median pH(H_2O) values, and extremes are listed in the following paragraphs in self-explanatory tables. It should be observed, that effects of land management practices are not considered in this broad study; these effects will be most marked on pH-values of the topsoil. The pH(H_2O) of all soil samples held in the WISE database ranges from 2.1 to 10.8, with a median value of 6.3 (N= 19,299). The medians and ranges observed for in the topsoils and subsoils of the various FAO-Unesco soil units are shown in Table 3.

For the sake of a logical presentation, the soil units of the legend have been grouped on the basis of generally accepted principles of soil formation (after FAO-Unesco, 1974 p. 10). A total of 106 soil units is considered at the second level of classification, as well as a number of miscellaneous units (e.g., salt flats and sand dunes). The Revised Legend (FAO-Unesco, 1990) could not be used in this study because the spatial database of WISE has been derived from the current, edited and digital version of the Soil Map of the World (FAO, 1991).

Table 3. Median and ranges in pH(H_2O) observed per FAO-Unesco soil unit.

FAO-Unesco unit	Code	0 to 30 cm				30 to 100 cm			
		N	Med.	Min.	Max.	N	Med.	Min.	Max.
Histosols	(O)	70	4.7	3.2	7.1	86	4.8	2.3	7.7
Rankers	(U)	14	5.6	4.3	6.5	2	4.8	4.5	6.5
Podzols	(P)	209	4.4	3.0	6.1	150	4.9	3.2	6.8
Acrisols	(A)	659	4.9	3.2	7.3	650	4.9	3.7	7.9
Ferralsols	(F)	520	5.0	3.0	7.6	498	5.1	3.8	8.0
Podzoluvisols	(D)	18	5.1	3.8	6.5	27	5.3	4.9	6.5
Nitosols	(N)	149	5.6	3.5	8.5	163	5.6	3.8	10.0
Andosols	(T)	306	5.8	4.0	7.5	356	6.0	4.5	8.2
Gleysols	(G)	478	5.7	3.4	9.1	476	6.3	3.5	9.3
Arenosols	(Q)	417	6.3	3.5	10.6	387	6.3	4.2	10.8
Cambisols	(B)	1094	6.1	3.2	9.7	1031	6.4	3.8	10.0
Regosols	(R)	201	6.3	3.8	9.0	107	6.4	4.2	9.0
Planosols	(W)	131	6.0	3.7	8.8	125	6.6	4.0	9.4
Luvisols	(L)	1142	6.4	3.2	10.5	1100	6.7	3.8	10.8
Phaeozems	(H)	367	6.4	4.0	8.7	447	7.0	4.3	8.9
Xerosols	(X)	240	7.6	4.5	9.0	204	7.8	5.1	9.6
Fluvisols	(J)	545	7.5	3.2	9.3	595	7.8	2.1	10.2
Lithosols	(I)	10	7.7	6.4	8.3	n.a	n.a	n.a	n.a
Kastanozems	(K)	52	7.5	5.8	9.0	50	8.0	6.9	9.1
Yermosols	(Y)	130	7.9	4.5	10.0	113	8.0	4.8	10.1
Vertisols	(V)	471	7.5	4.2	9.7	473	8.0	3.9	9.4
Chernozems	(C)	113	7.9	5.3	9.0	131	8.1	6.1	10.4
Greyzems	(M)	10	6.7	5.9	8.1	9	8.1	5.3	8.2
Rendzinas	(E)	58	7.6	6.4	8.4	16	8.1	7.3	9.0
Solonchaks	(Z)	166	8.2	6.3	10.6	146	8.3	6.4	10.8
Solonetz	(S)	140	8.2	4.7	10.5	141	8.7	4.7	10.5

Note: Soil units are ordered on basis of median (med.) pH(H_2O) of the subsoil, from acid to alkaline; N is number of samples; Min. and Max. are the extremes observed in the data set; Depth range is 0-10 cm for Lithosols and 30 cm to rock for Rendzinas and Rankers.

In the following tables, second level units are arranged in the sequence from "acid" to "alkaline", with reference to the subsoils in first instance. The symbol "≈" is used in the text to indicate a pH(H_2O) difference in the order of 0.4 units, "<" a difference of about 0.4 to 1.0 pH unit, and "<<" a difference of over 1.0 pH unit (between neighbouring second level soil units). Full frequency distributions of number of samples per pH(H_2O) class, as defined in Table 2, are included in the Appendix. The extremes in pH(H_2O) observed per soil unit can be large, reflecting both the natural variability in soil properties in space and time as well as restrictions imposed by the legend. Some soil units, such as the Vertisols (FAO-Unesco, 1974), may combine both "acid" and "alkaline" members an aspect that is now accounted for in the Revised Legend (FAO-Unesco, 1990).

a) **Histosols** (O) are soils whose formation is characterized by a strong accumulation of organic materials, generally associated with waterlogging. In terms of median pH, the following sequence is observed, going from acid to alkaline: (a) gelic (Ox) < dystric (Od) << eutric (Oe) for the topsoil, and (b) Od < Ox < Oe for the subsoil.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Od	47	4.5	3.2	6.9	59	4.5	2.3	6.6
Ox	5	3.9	3.6	4.8	9	5.3	3.8	5.8
Oe	18	5.8	4.9	7.1	18	5.8	4.6	7.7

* Note: Min. and Max. do not refer to horizons in the same profile.

b) Soils the formation of which is determined by particular properties of the parent materials, including the Arenosols, Andosols and Vertisols:

- **Arenosols** (Q) comprise coarse textured and weakly developed soils, some showing characteristics of argillic, cambic or oxic B horizons, and have less than 18% clay size minerals (excluding recent alluvial deposits, see Fluvisols). In terms of median pH, the following sequence is observed: (a) ferralic (Qf) < albic (Qa) < luvic (Ql) ≈ cambic (Qc) for the topsoil, and (b) Qf ≈ Qa < Ql < Qc for the subsoil.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Qf	117	5.6	3.9	9.0	106	5.4	4.3	7.5
Qa	22	6.1	3.5	8.4	23	5.6	4.9	8.4
Ql	41	6.5	4.7	8.3	51	6.2	4.2	7.7
Qc	237	6.6	3.5	10.6	207	6.9	4.3	10.8

- **Andosols** (T) are derived from volcanic deposits, rich in volcanic glass. In terms of median pH, the following sequence is observed: (a) humic (Th) < ochric (To) ≈ mollic (Tm) ≈ vitric (Tv) for the topsoil, and (b) Th < Tv ≈ To ≈ Tm for the subsoil.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Th	160	5.5	4.0	6.6	204	5.9	4.5	7.1
Tv	60	6.1	4.6	7.4	63	6.2	4.6	7.0
To	39	5.8	3.8	7.4	29	6.3	4.6	7.8
Tm	48	6.1	5.2	7.5	60	6.3	5.0	8.2

- **Vertisols** (V) are dark coloured, smectite-rich, swelling and deeply cracking clay soils. In terms of median pH, the following sequence is observed: (a) pellic (Vp) < chromic (Vc) for the topsoil, and (b) Vp ≈ Vc for the subsoil.

FAO unit	0 to 30 cm N	Med.	Min.	Max.	30 to 100 cm N	Med.	Min.	Max.
Vp	213	7.2	5.1	9.7	184	7.8	5.0	9.4
Vc	258	7.9	4.2	9.1	289	8.1	3.9	9.3

c) Soils the formation of which is strongly influenced by the relief and physiographic setting, including the Fluvisols, Gleysols, Regosols, Lithosols, Rendzinas and Rankers:

- **Fluvisols** (J) are recent alluvial soils, derived from fluviatile, marine, lacustrine, or colluvial materials. Profiles are commonly stratified, and show an irregular decrease in organic carbon content with depth. In terms of median pH, the following sequence is observed for: (a) the topsoil: thionic (Jt) ≈ dystric (Jd) << eutric (Je) << calcaric (Jc), and (b) the subsoil: Jt << Jd << Je < Jc.

FAO unit	0 to 30 cm N	Med.	Min.	Max.	30 to 100 cm N	Med.	Min.	Max.
Jt	45	4.8	3.2	7.4	43	3.8	2.1	7.4
Jd	54	4.8	3.6	6.4	61	5.0	4.0	7.2
Je	251	7.0	4.7	9.3	257	7.5	5.3	9.4
Jc	195	8.1	6.9	9.2	234	8.1	7.2	10.2

- **Gleysols** (G) are dominated by hydromorphic soil forming processes. In terms of median pH, the following sequence is observed: (a) dystric (Gd) ≈ humic (Gh) ≈ plinthic (Gp) < gelic (Gx) < eutric (Ge) < mollic (Gm) << calcaric (Gc) for the topsoil, and (b) Gd ≈ Gp ≈ Gh < Ge ≈ Gx ≈ Gm << Gc for the subsoil.

FAO unit	0 to 30 cm N	Med.	Min.	Max.	30 to 100 cm N	Med.	Min.	Max.
Gd	122	5.0	3.5	6.5	116	5.0	3.5	7.8
Gp	9	5.4	4.7	6.4	13	5.1	4.8	6.0
Gh	52	5.1	3.4	7.5	49	5.2	3.9	8.1
Ge	169	6.2	4.0	8.5	153	6.7	4.4	8.4
Gx	17	5.7	4.5	8.0	10	7.0	4.7	8.3
Gm	82	6.6	3.8	9.1	106	7.2	3.9	9.3
Gc	27	7.5	5.0	8.8	29	8.4	6.9	8.9

- **Regosols** (R) are weakly developed soils over unconsolidated parent materials, excluding recent alluvial deposits (see Fluvisols) and coarse textured soils (see Arenosols). In terms of median pH, the following sequence is observed for both the subsoil and topsoil: dystric (Rd) ≈ gelic (Rx) < eutric (Re) << calcaric (Rc).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Rd	60	5.1	3.8	7.1	31	5.4	4.2	6.6
Rx	3	5.6	5.3	7.9	2	6.2	5.9	7.9
Re	92	6.4	4.8	8.7	49	6.7	4.8	9.0
Rc	46	8.0	6.3	9.0	25	8.2	7.6	8.7

- **Lithosols** (I) are shallow soils, less than 10 cm deep, formed over hard, continuous rock. Depending on the nature of the parent rock, the pH range can vary from acid (e.g., granite) to basic (e.g., basalt). The available Lithosols are mainly derived from basic parent materials.

FAO unit	0 to 10 cm			
	N	Med.	Min.	Max.
I	10	7.7	6.4	8.3

- **Rendzinas** (E) are predominantly shallow soils, with a mollic A horizon, formed over calcareous parent materials.

FAO unit	0 to 30 cm				30 cm to rock			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
E	58	7.6	6.4	8.4	16	8.1	7.3	9.0

- **Rankers** (U) are predominantly shallow soils, with an umbric A horizon, formed over acid, siliceous rocks.

FAO unit	0 to 30 cm				30 cm to rock			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
U	14	5.6	4.3	6.5	2	4.8	4.5	6.5

d) Soils the formation of which is conditioned by a limited pedogenetic age or by rejuvenation:

- **Cambisols** (B), are characterized by weak weathering in situ reflected by a change in colour, texture or consistence, without migration of weathering products within the profile. In terms of median pH, the following sequence is observed for both the topsoil and subsoil: gelic (Bx) ≈ dystric (Bd) ≈ humic (Bh) ≈ ferralic (Bf) < gleyic (Bg) < eutric (Be) < chromic (Bc) ≈ vertic (Bv) < calcic (Bk).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Bx	40	5.0	3.2	7.3	29	5.1	3.8	7.5
Bd	195	5.1	3.3	7.3	166	5.2	4.0	7.2
Bh	80	5.1	3.6	6.2	86	5.3	4.4	6.5
Bf	94	5.1	3.9	7.8	92	5.3	4.1	7.7
Bg	99	5.8	4.0	8.9	101	6.2	4.2	9.9
Be	247	6.7	4.2	8.9	224	6.9	4.5	8.6
Bc	53	6.9	4.2	8.3	59	7.2	4.5	8.7
Bv	73	6.9	4.9	9.7	76	7.4	5.6	10.0
Bk	213	8.1	5.4	9.5	198	8.2	6.0	10.0

e) Soils with clay illuviation the formation of which is markedly influenced by a temperate, humid tropical or subtropical climate, including the Luvisols, Acrisols and Nitosols:

- **Luvisols** (L) have clear clay illuviation in to the subsoil (argillic B horizon), and a high base saturation in the subsoil (measured in 1 *M* NH_4OAc). In the Revised Legend (FAO-Unesco, 1990) a further differentiation is made into Luvisols (LV) and Lixisols (LX) on the basis of cation exchange capacity of the clay fraction. In terms of median pH, the following sequence is observed: (a) plinthic (Lp) ≈ ferric (Lf) < gleyic (Lg) ≈ orthic (Lo) ≈ albic (La) ≈ chromic (Lc) < vertic (Lv) < calcic (Lk) for the topsoil, and (b) Lf ≈ Lp < Lg ≈ Lc ≈ Lo < Lv ≈ La << Lk for the subsoil.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Lf	197	5.9	4.1	8.3	180	5.8	4.4	8.0
Lp	22	5.8	4.7	7.2	23	6.0	4.9	6.6
Lg	172	6.1	3.2	9.0	173	6.5	4.0	9.9
Lc	175	6.4	4.4	8.5	158	6.5	4.7	8.8
Lo	275	6.3	3.2	9.1	271	6.7	3.8	9.0
Lv	26	7.0	5.0	8.6	23	7.0	5.1	8.8
La	62	6.4	4.6	7.9	55	7.1	4.8	10.7
Lk	213	8.0	5.0	10.5	217	8.3	5.9	10.8

- **Acrisols** (A) have clear clay illuviation in to the subsoil (argillic B horizon), and a low base saturation in the subsoil. They are more strongly leached than the Luvisols, but they are not weathered strongly enough (CEC > 24 $cmol_c$ kg^{-1} clay), to classify as a Ferralsol. By definition, the base saturation in the subsoil of Acrisols is less than that of the Luvisols. In the Revised Legend (FAO, 1990), a further division has been made that takes into account the cation exchange capacity (Acrisols (AC) and Alisols (AL), with CEC of < and > 24 $cmol_c$ kg^{-1} clay, respectively). In terms of median pH, all subunits have very strongly acid pH in the topsoil and subsoil, with no marked differences between the subunits.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Ag	50	4.7	3.6	6.4	48	4.7	4.1	7.9
Ap	75	4.7	3.4	7.3	78	4.8	3.9	5.8
Af	247	5.0	3.6	7.2	223	4.9	3.9	6.7
Ao	141	4.9	3.2	6.9	142	5.0	4.0	6.6
Ah	146	4.9	3.5	6.7	159	5.1	3.7	6.6

- **Nitosols** (N) are mainly tropical soils with thick argillic B horizons with so-called shiny clay skins or peds. In terms of median pH, the following sequence is observed for both the topsoil and subsoil: dystric (Nd) ≈ humic (Nh) < eutric (Ne).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Nd	48	4.9	3.5	7.1	50	5.0	3.8	6.2
Nh	25	5.2	4.6	5.8	33	5.3	4.6	6.2
Ne	76	6.2	4.9	8.5	80	6.4	4.8	10.0

f) Soils having an oxic B horizon:

- **Ferralsols** (F) are the strongly weathered soils of the humid tropics, that have oxic B horizons caused by the destruction of the sorptive complex and accumulation of hydrated oxides as demonstrated by the low CEC (< 16 $cmol_c$ kg^{-1} by NH_4OAc). In terms of median pH, the following general sequence is observed: xanthic (Fx) ≈ acric (Fa) ≈ humic (Fh) < orthic (Fo) ≈ plinthic (Fp) ≈ rhodic (Fr).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Fx	112	4.5	3.3	6.2	104	4.8	3.8	5.9
Fa	45	4.7	3.9	5.9	41	5.1	4.0	6.7
Fh	96	4.9	3.0	6.6	107	5.1	3.9	6.9
Fo	170	5.0	3.5	7.4	157	5.2	4.2	7.9
Fp	15	4.9	4.1	6.2	19	5.4	4.4	6.2
Fr	82	5.5	4.0	7.6	70	5.5	3.8	8.0

g) Soils the formation of which is conditioned by steppe climates and which are characterized also by a surface enrichment of humus, saturated in bases. These include the Chernozems, Greyzems, Kastanozems and Phaeozems:

- **Chernozems** (C) are fertile soils of the temperate steppes. Typically, they have thick, dark mollic A horizons in which organic matter accumulates in the presence of calcium carbonate. Irrespective of the sub-units and depth considered, the Chernozems are slightly alkaline and moderately alkaline pH.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Ch	34	7.7	6.3	8.5	36	7.8	6.1	8.5
Cg	-	7.7	-	-	-	8.1	-	-
Cl	22	7.6	5.8	9.0	27	8.1	6.5	10.4
Ck	57	8.1	5.3	9.0	68	8.2	6.4	9.8

- **Greyzems** (M) have a mollic A horizon, with an absence of coatings on sand and silt grains on ped surfaces. They occur mainly in cool temperate zones. Based on the still limited data set the pH of the subsoil is in the range from slightly acid to moderately alkaline.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Mg	-	6.7	-	-	1	6.2	6.2	6.2
Mo	10	6.7	5.9	8.1	8	8.1	5.3	8.2

- **Kastanozems** (K), the chestnut or brown temperate steppe soils, resemble Chernozems, but with less thick mollic horizons and often carbonate or gypsum rich subsoils. In terms of median subsoil pH, the following sequence is observed: luvic (Kl) < haplic (Kh) < calcic (Kk).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Kl	2	5.9	5.8	6.0	3	7.4	6.9	7.8
Kh	25	7.4	6.6	8.0	22	7.7	7.3	8.4
Kk	25	7.9	6.8	9.0	25	8.3	7.2	9.1

- **Phaeozems** (H) are similar to Chernozems, and occur mainly in slightly more humid areas than the Greyzems, Kastanozems and Chernozems. The general pH sequence is: humic (Hh) ≈ gleyic (Hg) ≈ luvic (Hl) << calcaric (Hc).1

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Hh	122	6.4	4.0	8.4	155	6.7	4.6	8.9
Hg	38	6.0	4.4	8.1	50	6.9	4.3	8.2
Hl	164	6.3	4.7	8.7	184	6.9	5.3	8.9
Hc	43	7.9	6.7	8.7	58	8.2	7.4	8.8

h) Soils the formation of which is conditioned by humid cool to temperate climates, including the Podzols, Podzoluvisols and Planosols:

- **Podzols** (P) are strongly acid to extremely acid soils with spodic B horizons, in which illuviation of organic matter and/or sesquioxides prevails. The median pH(H_2O) values always are in the very strongly acid and acid range.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Pg	32	4.7	3.6	5.8	33	4.8	3.8	6.1
Ph	38	4.2	3.0	4.7	35	4.8	3.6	6.8
Po	79	4.3	3.1	6.1	50	5.0	3.2	6.5
Pp	28	4.2	3.2	5.9	17	5.0	4.1	5.6
Pf	1	3.8	3.8	3.8	1	5.3	5.3	5.3
Pl	31	4.9	3.5	6.1	14	5.4	4.5	6.3

- **Podzoluvisols** (D) are intermediate in their properties to the Podzols and Luvisols. They are characterized by deep tonguing of the eluvial E horizon into the argillic B horizon. The subsoil is strongly acid and maximum pH(H_2O) values remain below 7.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Dd	7	4.9	3.8	5.3	10	5.2	4.9	5.8
Dg	2	6.0	5.9	6.1	2	5.3	5.0	6.0
De	9	5.1	4.7	6.5	15	5.3	5.0	6.5

- **Planosols** (W) show a strong textural differentiation, with a bleached albic horizon caused by clay destruction in the surface layer, and hydromorphic properties in the eluvial horizon. In terms of median pH, the following sequence is observed for the subsoil: dystric (Wd) < eutric (We) < humic (Wh) ≈ gelic (Wx) < mollic (Wm) ≈ solodic (Ws).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Wd	24	4.2	3.7	5.7	23	4.6	4.0	6.3
We	41	5.9	4.3	8.8	44	6.4	4.4	9.0
Wx	-	6.0	-	-	-	7.0	-	-
Wh	-	6.0	-	-	-	7.0	-	-
Wm	18	6.0	5.2	6.8	18	7.6	5.2	8.8
Ws	48	6.4	3.9	8.1	40	7.8	4.9	9.4

i) Soils the formation of which is strongly influenced by an arid or semi-arid climate, as reflected by an accumulation of salts. Lack of leaching leaves a high base status in these soils, which include the Solonchaks and Solonetz:

- **Solonchaks** (Z) have high salinity and are moderately alkaline to strongly alkaline. Minimum pH(H_2O) encountered in the WISE data set is 6.3.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Zt	7	7.7	7.1	8.6	4	7.8	7.6	7.9
Zm	5	7.8	7.5	8.4	5	8.1	7.6	8.8
Zo	106	8.1	6.7	10.5	98	8.2	6.4	10.8
Zg	48	8.3	6.3	10.6	39	8.5	7.2	10.7

- **Solonetz** (S) are sodic soils with a natric B horizon. Subsoils mostly are moderately to strongly alkaline.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Sm	13	6.6	5.2	9.0	13	8.4	7.8	9.6
Sg	33	8.0	4.7	9.9	39	8.8	4.8	10.5
So	94	8.4	5.0	10.5	89	8.8	4.7	10.4

j) Soils which have been defined mainly on their occurrence in very dry areas and as a result have low organic carbon contents:

- **Xerosols** (X) are desert and semi-desert soils with a weak ochric A horizon. The soil pH is slightly alkaline and moderately alkaline.

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Xl	146	7.3	4.5	8.9	131	7.8	5.1	9.4
Xy	17	7.9	7.3	8.9	17	7.8	7.0	9.1
Xh	38	8.0	5.9	8.9	30	8.0	5.5	9.1
Xk	39	7.9	7.2	9.0	26	8.3	7.2	9.6

- **Yermosols** (Y) have a very weak ochric A horizon, and are formed under arid conditions. The soil pH ranges from neutral for the takyric Yermosols (Yt) to moderately alkaline for the haplic Yermosols (Yh).

FAO unit	0 to 30 cm				30 to 100 cm			
	N	Med.	Min.	Max.	N	Med.	Min.	Max.
Yt	3	7.2	6.9	7.4	2	6.9	6.9	7.0
Yy	35	7.8	7.1	8.6	26	7.8	7.4	8.6
Yl	42	7.5	4.5	9.3	37	7.9	4.8	8.9
Yk	32	8.0	7.0	8.8	28	8.1	7.0	8.5
Yh	18	8.1	4.7	10.0	20	8.2	5.9	10.1

4.2 Agricultural and environmental interpretation

As discussed by Russell (1973) and Landon (1991) pH values do not have a precise significance in agricultural practice. Nonetheless, general relationships between pH and nutrient availability to crops and selected environmental problems can be identified, as is shown in Table 4.

Table 4. Broad interpretation of soil pH(H_2O) classes. (After Landon (1991) and Mengel and Kirkby (1982))

pH(H_2O)	General interpretation
pH ≤ 5.5	*Strongly acid soils*: possible Al-toxicity and excess availability of Co, Cu, Fe, Mn and Zn; deficient in Ca, K, N, Mg, P and S; B deficient below pH of 5; Mo becomes more available with decreasing pH; bacterial and actinomycete activity is reduced, and predominance of fungi; mineralisation of organic matter and nitrification are restricted; below a pH of 3.0, functioning of cell membranes is impaired, resulting in leakage of elements.
5.5 ≤ pH < 7.3	*Moderately acid, slightly acid and neutral soils*: preferred pH range for most crops, lower end of range, however, too acidic for some; in the 6.0-7.0 range, phosphorus fixation is at a minimum; a neutral pH favours the fixation of molecular N by free living soil micro-organisms and by symbiotic microorganisms; above pH 7.0, the availability of Fe, Mn, Zn, Cu and Co declines.
7.3 ≤ pH < 8.5	*Slightly alkaline and moderately alkaline soils:* above pH of 7.0, increasing availability of Co, Cu, Fe, Mn and Zn; increasing risk of ammonia volatilization; first increasing availability of P and B, but deficiencies may occur at higher pH values; insoluble Ca-phosphates may be formed at higher pH; ECe values are generally high (> 4 dS m^{-1}) at higher pH values.
8.5 ≤ pH	*Strongly alkaline soils*: Ca and Mg are liable to become unavailable to most crops; often high in Na resulting in toxicity and structural damage; toxicity of bicarbonate and other anions; possible B toxicity common in saline and/or sodic soils; availability of most micronutrients and of Fe, Mn, Zn, Cu and Co is reduced, except for Mo; decreased microbial activity.

Soil pH affects the availability of most major and minor plant nutrients. High hydrogen concentrations favour the weathering of minerals resulting in a release of various ions such as K^{+}, Mg^{2+}, Ca^{2+}, Mn^{2+} and Cu^{2+}, and ultimately Al^{3+}. The solubility of salts including carbonates, phosphates, sulphates is higher in the lower pH range. Soil pH and redox conditions are also of great importance for the reaction processes of heavy metals (Alloway, 1990), and in controlling the production, absorbtion and emission of radiatively active trace gases (Batjes and Bridges, 1992). A lowering of soil pH upon acid deposition or a change in land use, for instance, will increase heavy-metal solubility, decrease cation exchange capacity and alter soil microbial populations.

The pH tolerance limits of different plants and plant cultivars vary widely, but for most commercial crops a neutral range is considered most suitable with a pH(H_2O) (1:2.5 soil:water) of between 6.3 and 7.5. Generally, it is not the soil pH *per se* that is the growth limiting factor, but rather one or more secondary factors which are pH dependent (Mengel and Kirkby, 1982). For example, iron is not usually deficient in soils, but Fe^{3+} availability in aqueous solution of calcareous soils can be insufficient for plant growth, depending though on the species or variety grown (Brown, 1978).

5. Conclusions

This study permitted an improved characterization of the pH properties of the soil units of the Soil Map of the World, using a larger selection of soil profiles than has been available so far (FAO-Unesco, 1971-1981). Nonetheless, some soil units are under-represented in the WISE database, particularly the Greyzems and Podzoluvisols. The information presented for these soil units will be fine-tuned as the number of profiles available per second level soil unit in the WISE database increases. The median pH(H_2O) values listed in the Appendix can easily be linked to the corrected and digital version of the Soil Map of the World (FAO, 1991), using the soil unit descriptors.

A proposed future application of the WISE database would be to rate soil fertility by FAO soil unit based on the joint analysis of soil pH, soil organic carbon content, total nitrogen, cation exchange capacity, and soil phosphorus data. Also, improved characterizations for soil rooting depth and moisture holding capacity can now be developed, based on a larger number of soil profiles than has been available so far. Using this updated information, "soil reduction" factors in global environmental studies (e.g., Chadwick and Kuylenstierna, 1990; Bouwman *et al.*, 1994; Leemans and Van den Born, 1994) may ultimately be fine-tuned. Once this has been done, the potential of the WISE database in assessing soil gaseous emissions potentials and the vulnerability of soils to chemicals pollution can be further exploited.

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Appendix Median and range in soil pH(H_2O) per FAO-Unesco soil unit

(N= number of observations; Med.= median; Min.= minimum; Max.= maximum)

FAO unit	depth	N	Med.	Min.	Max.	pH_H2O <=4.0	4.4-5.5	5.6-7.3	7.3-8.5	8.5<	status
Alfisols											
A	TOP	659	4.9	3.2	7.3	62	470	127	0	0	C
A	SUB	650	4.9	3.7	7.9	13	547	89	1	0	C
Af	TOP	247	5.0	3.6	7.2	14	168	65	0	0	C
Af	SUB	223	4.9	3.9	6.7	3	188	32	0	0	C
Ag	TOP	50	4.7	3.6	6.4	9	32	9	0	0	C
Ag	SUB	48	4.7	4.1	7.9	0	42	5	1	0	C
Ah	TOP	146	4.9	3.5	6.7	8	117	21	0	0	C
Ah	SUB	159	5.1	3.7	6.6	2	123	34	0	0	C
Ao	TOP	141	4.9	3.2	6.9	16	101	24	0	0	C
Ao	SUB	142	5.0	4.0	6.6	4	122	16	0	0	C
Ap	TOP	75	4.7	3.4	7.3	15	52	8	0	0	C
Ap	SUB	78	4.8	3.9	5.8	4	72	2	0	0	C
Cambisols											
B	TOP	1094	6.1	3.2	9.7	33	358	377	288	38	C
B	SUB	1031	6.4	3.8	10.0	6	307	342	319	57	C
Bc	TOP	53	6.9	4.2	8.3	0	6	33	14	0	C
Bc	SUB	59	7.2	4.5	8.7	0	11	23	20	5	C
Bd	TOP	195	5.1	3.3	7.3	18	137	40	0	0	C
Bd	SUB	166	5.2	4.0	7.2	2	113	51	0	0	C
Be	TOP	247	6.7	4.2	8.9	0	24	141	77	5	C
Be	SUB	224	6.9	4.5	8.6	0	24	108	89	3	C
Bf	TOP	94	5.1	3.9	7.8	6	64	22	2	0	C
Bf	SUB	92	5.3	4.1	7.7	0	59	30	3	0	C
Bg	TOP	99	5.8	4.0	8.9	1	34	51	12	1	C
Bg	SUB	101	6.2	4.2	9.9	0	30	45	20	6	C
Bh	TOP	80	5.1	3.6	6.2	3	59	18	0	0	C
Bh	SUB	86	5.3	4.4	6.5	0	54	32	0	0	C
Bk	TOP	213	8.1	5.4	9.5	0	1	24	166	22	C
Bk	SUB	198	8.2	6.0	10.0	0	0	11	153	34	C
Bv	TOP	73	6.9	4.9	9.7	0	6	40	17	10	C
Bv	SUB	76	7.4	5.6	10.0	0	0	35	32	9	C
Bx	TOP	40	5.0	3.2	7.3	5	27	8	0	0	C
Bx	SUB	29	5.1	3.8	7.5	4	16	7	2	0	C
Chernozems											
C	TOP	113	7.9	5.3	9.0	0	1	27	67	18	C
C	SUB	131	8.1	6.1	10.4	0	0	16	89	26	C
Cg	TOP	0	7.7	-	-	-	-	-	-	-	Z
Cg	SUB	0	8.1	-	-	-	-	-	-	-	Z
Ch	TOP	34	7.7	6.3	8.5	0	0	11	23	0	C
Ch	SUB	36	7.8	6.1	8.5	0	0	7	29	0	C
Ck	TOP	57	8.1	5.3	9.0	0	1	8	33	15	C
Ck	SUB	68	8.2	6.4	9.8	0	0	3	46	19	C
Cl	TOP	22	7.6	5.8	9.0	0	0	8	11	3	C
Cl	SUB	27	8.1	6.5	10.4	0	0	6	14	7	C

FAO unit	depth	N	Med.	Min.	Max.	pH_H2O <=4.0	4.4-5.5	5.6-7.3	7.3-8.5	8.5<	status
Podzoluvisols											
D	TOP	18	5.1	3.8	6.5	1	11	6	0	0	C
D	SUB	27	5.3	4.9	6.5	0	20	7	0	0	C
Dd	TOP	7	4.9	3.8	5.3	1	6	0	0	0	C
Dd	SUB	10	5.2	4.9	5.8	0	8	2	0	0	C
De	TOP	9	5.1	4.7	6.5	0	5	4	0	0	C
De	SUB	15	5.3	5.0	6.5	0	11	4	0	0	C
Dg	TOP	2	6.0	5.9	6.1	0	0	2	0	0	C
Dg	SUB	2	5.3	5.0	6.0	0	1	1	0	0	C
Rendzinas											
E	TOP	58	7.6	6.4	8.4	0	0	17	41	0	C
E	SUB	16	8.1	7.3	9.0	0	0	1	13	2	C
Ferralsols											
F	TOP	520	5.0	3.0	7.6	39	367	111	3	0	C
F	SUB	498	5.1	3.8	8.0	8	361	124	5	0	C
Fa	TOP	45	4.7	3.9	5.9	1	42	2	0	0	C
Fa	SUB	41	5.1	4.0	6.7	1	31	9	0	0	C
Fh	TOP	96	4.9	3.0	6.6	6	74	16	0	0	C
Fh	SUB	107	5.1	3.9	6.9	2	86	19	0	0	C
Fo	TOP	170	5.0	3.5	7.4	8	119	42	1	0	C
Fo	SUB	157	5.2	4.2	7.9	0	107	48	2	0	C
Fp	TOP	15	4.9	4.1	6.2	0	13	2	0	0	C
Fp	SUB	19	5.4	4.4	6.2	0	12	7	0	0	C
Fr	TOP	82	5.5	4.0	7.6	1	42	37	2	0	C
Fr	SUB	70	5.5	3.8	8.0	2	33	32	3	0	C
Fx	TOP	112	4.5	3.3	6.2	23	77	12	0	0	C
Fx	SUB	104	4.8	3.8	5.9	3	92	9	0	0	C
Gleysols											
G	TOP	478	5.7	3.4	9.1	17	191	220	46	4	C
G	SUB	476	6.3	3.5	9.3	13	157	186	109	11	C
Gc	TOP	27	7.5	5.0	8.8	0	4	8	13	2	C
Gc	SUB	29	8.4	6.9	8.9	0	0	1	21	7	C
Gd	TOP	122	5.0	3.5	6.5	7	90	25	0	0	C
Gd	SUB	116	5.0	3.5	7.8	9	80	26	1	0	C
Ge	TOP	169	6.2	4.0	8.5	2	35	116	16	0	C
Ge	SUB	153	6.7	4.4	8.4	0	23	92	38	0	C
Gh	TOP	52	5.1	3.4	7.5	6	34	11	1	0	C
Gh	SUB	49	5.2	3.9	8.1	1	33	12	3	0	C
Gm	TOP	82	6.6	3.8	9.1	2	15	48	15	2	C
Gm	SUB	106	7.2	3.9	9.3	3	8	49	42	4	C
Gp	TOP	9	5.4	4.7	6.4	0	5	4	0	0	C
Gp	SUB	13	5.1	4.8	6.0	0	11	2	0	0	C
Gx	TOP	17	5.7	4.5	8.0	0	8	8	1	0	C
Gx	SUB	10	7.0	4.7	8.3	0	2	4	4	0	C

FAO unit	depth	N	Med.	Min.	Max.	<=4.0	4.4-5.5	5.6-7.3	7.3-8.5	8.5<	status
						pH_H2O					
Phaeozems											
H	TOP	367	6.4	4.0	8.7	1	48	244	69	5	C
H	SUB	447	7.0	4.3	8.9	0	29	253	139	26	C
Hc	TOP	43	7.9	6.7	8.7	0	0	3	37	3	C
Hc	SUB	58	8.2	7.4	8.8	0	0	0	40	18	C
Hg	TOP	38	6.0	4.4	8.1	0	12	24	2	0	C
Hg	SUB	50	6.9	4.3	8.2	0	9	28	13	0	C
Hh	TOP	122	6.4	4.0	8.4	1	14	92	15	0	C
Hh	SUB	155	6.7	4.6	8.9	0	16	102	36	1	C
Hl	TOP	164	6.3	4.7	8.7	0	22	125	15	2	C
Hl	SUB	184	6.9	5.3	8.9	0	4	123	50	7	C
Lithosols											
I	TOP	10	7.7	6.4	8.3	0	0	3	7	0	C
Fluvisols											
J	TOP	545	7.5	3.2	9.3	13	97	148	250	37	C
J	SUB	595	7.8	2.1	10.2	28	64	130	325	48	C
Jc	TOP	195	8.1	6.9	9.2	0	0	7	166	22	C
Jc	SUB	234	8.1	7.2	10.2	0	0	4	199	31	C
Jd	TOP	54	4.8	3.6	6.4	5	41	8	0	0	C
Jd	SUB	61	5.0	4.0	7.2	2	42	17	0	0	C
Je	TOP	251	7.0	4.7	9.3	0	31	122	83	15	C
Je	SUB	257	7.5	5.3	9.4	0	8	108	124	17	C
Jt	TOP	45	4.8	3.2	7.4	8	25	11	1	0	C
Jt	SUB	43	3.8	2.1	7.4	26	14	1	2	0	C
Kastanozems											
K	TOP	52	7.5	5.8	9.0	0	0	19	30	3	C
K	SUB	50	8.0	6.9	9.1	0	0	3	40	7	C
Kh	TOP	25	7.4	6.6	8.0	0	0	11	14	0	C
Kh	SUB	22	7.7	7.3	8.4	0	0	1	21	0	C
Kk	TOP	25	7.9	6.8	9.0	0	0	6	16	3	C
Kk	SUB	25	8.3	7.2	9.1	0	0	1	17	7	C
Kl	TOP	2	5.9	5.8	6.0	0	0	2	0	0	C
Kl	SUB	3	7.4	6.9	7.8	0	0	1	2	0	C
Luvisols											
L	TOP	1142	6.4	3.2	10.5	7	211	661	215	48	C
L	SUB	1100	6.7	3.8	10.8	5	183	503	304	105	C
La	TOP	62	6.4	4.6	7.9	0	10	43	9	0	C
La	SUB	55	7.1	4.8	10.7	0	9	22	19	5	C
Lc	TOP	175	6.4	4.4	8.5	0	35	118	22	0	C
Lc	SUB	158	6.5	4.7	8.8	0	29	94	32	3	C
Lf	TOP	197	5.9	4.1	8.3	0	52	141	4	0	C
Lf	SUB	180	5.8	4.4	8.0	0	52	122	6	0	C
Lg	TOP	172	6.1	3.2	9.0	2	48	100	19	3	C
Lg	SUB	173	6.5	4.0	9.9	1	41	78	41	12	C
Lk	TOP	213	8.0	5.0	10.5	0	3	53	115	42	C
Lk	SUB	217	8.3	5.9	10.8	0	0	23	117	77	C
Lo	TOP	275	6.3	3.2	9.1	5	54	173	41	2	C
Lo	SUB	271	6.7	3.8	9.0	4	39	137	84	7	C
Lp	TOP	22	5.8	4.7	7.2	0	5	17	0	0	C
Lp	SUB	23	6.0	4.9	6.6	0	8	15	0	0	C
Lv	TOP	26	7.0	5.0	8.6	0	4	16	5	1	C
Lv	SUB	23	7.0	5.1	8.8	0	5	12	5	1	C

(App.1, cont.)

FAO unit	depth	N	Med.	Min.	Max.	<=4.0	4.4-5.5	pH_H2O 5.6-7.3	7.3-8.5	8.5<	status
Greyzems											
M	TOP	10	6.7	5.9	8.1	0	0	6	4	0	C
M	SUB	9	8.1	5.3	8.2	0	3	1	5	0	C
Mg	TOP	0	6.7	-	-	-	-	-	-	-	Z
Mg	SUB	1	6.2	6.2	6.2	0	0	1	0	0	C
Mo	TOP	10	6.7	5.9	8.1	0	0	6	4	0	C
Mo	SUB	8	8.1	5.3	8.2	0	3	0	5	0	C
Nitosols											
N	TOP	149	5.6	3.5	8.5	7	61	75	6	0	C
N	SUB	163	5.6	3.8	10.0	4	71	78	8	2	C
Nd	TOP	48	4.9	3.5	7.1	7	29	12	0	0	C
Nd	SUB	50	5.0	3.8	6.2	4	36	10	0	0	C
Ne	TOP	76	6.2	4.9	8.5	0	10	60	6	0	C
Ne	SUB	80	6.4	4.8	10.0	0	12	58	8	2	C
Nh	TOP	25	5.2	4.6	5.8	0	22	3	0	0	C
Nh	SUB	33	5.3	4.6	6.2	0	23	10	0	0	C
Histosols											
O	TOP	70	4.7	3.2	7.1	17	35	18	0	0	C
O	SUB	86	4.8	2.3	7.7	20	48	16	2	0	C
Od	TOP	47	4.5	3.2	6.9	14	28	5	0	0	C
Od	SUB	59	4.5	2.3	6.6	19	38	2	0	0	C
Oe	TOP	18	5.8	4.9	7.1	0	5	13	0	0	C
Oe	SUB	18	5.8	4.6	7.7	0	3	13	2	0	C
Ox	TOP	5	3.9	3.6	4.8	3	2	0	0	0	C
Ox	SUB	9	5.3	3.8	5.8	1	7	1	0	0	C
Podzols											
P	TOP	209	4.4	3.0	6.1	62	133	14	0	0	C
P	SUB	150	4.9	3.2	6.8	7	117	26	0	0	C
Pf	TOP	1	3.8	3.8	3.8	1	0	0	0	0	C
Pf	SUB	1	5.3	5.3	5.3	0	1	0	0	0	C
Pg	TOP	32	4.7	3.6	5.8	7	23	2	0	0	C
Pg	SUB	33	4.8	3.8	6.1	1	24	8	0	0	C
Ph	TOP	38	4.2	3.0	4.7	15	23	0	0	0	C
Ph	SUB	35	4.8	3.6	6.8	2	32	1	0	0	C
Pl	TOP	31	4.9	3.5	6.1	4	20	7	0	0	C
Pl	SUB	14	5.4	4.5	6.3	0	8	6	0	0	C
Po	TOP	79	4.3	3.1	6.1	27	48	4	0	0	C
Po	SUB	50	5.0	3.2	6.5	4	36	10	0	0	C
Pp	TOP	28	4.2	3.2	5.9	8	19	1	0	0	C
Pp	SUB	17	5.0	4.1	5.6	0	16	1	0	0	C
Arenosols											
Q	TOP	417	6.3	3.5	10.6	7	99	237	60	14	C
Q	SUB	387	6.3	4.2	10.8	0	115	180	64	28	C
Qa	TOP	22	6.1	3.5	8.4	2	5	13	2	0	C
Qa	SUB	23	5.6	4.9	8.4	0	11	10	2	0	C
Qc	TOP	237	6.6	3.5	10.6	4	38	128	54	13	C
Qc	SUB	207	6.9	4.3	10.8	0	35	86	58	28	C
Qf	TOP	117	5.6	3.9	9.0	1	53	61	1	1	C
Qf	SUB	106	5.4	4.3	7.5	0	60	45	1	0	C
Ql	TOP	41	6.5	4.7	8.3	0	3	35	3	0	C
Ql	SUB	51	6.2	4.2	7.7	0	9	39	3	0	C

(App.1, cont.)

FAO unit	depth	N	Med.	Min.	Max.	pH_H2O <=4.0	4.4-5.5	5.6-7.3	7.3-8.5	8.5<	status
Regosols											
R	TOP	201	6.3	3.8	9.0	5	52	83	51	10	C
R	SUB	107	6.4	4.2	9.0	0	30	35	38	4	C
Rc	TOP	46	8.0	6.3	9.0	0	0	4	35	7	C
Rc	SUB	25	8.2	7.6	8.7	0	0	0	23	2	C
Rd	TOP	60	5.1	3.8	7.1	5	36	19	0	0	C
Rd	SUB	31	5.4	4.2	6.6	0	19	12	0	0	C
Re	TOP	92	6.4	4.8	8.7	0	15	59	15	3	C
Re	SUB	49	6.7	4.8	9.0	0	11	22	14	2	C
Rx	TOP	3	5.6	5.3	7.9	0	1	1	1	0	C
Rx	SUB	2	6.2	5.9	7.9	0	0	1	1	0	C
Solonetz											
S	TOP	140	8.2	4.7	10.5	0	9	31	46	54	C
S	SUB	141	8.7	4.7	10.5	0	3	3	54	81	C
Sg	TOP	33	8.0	4.7	9.9	0	2	13	7	11	C
Sg	SUB	39	8.8	4.8	10.5	0	1	0	11	27	C
Sm	TOP	13	6.6	5.2	9.0	0	3	5	2	3	C
Sm	SUB	13	8.4	7.8	9.6	0	0	0	8	5	C
So	TOP	94	8.4	5.0	10.5	0	4	13	37	40	C
So	SUB	89	8.8	4.7	10.4	0	2	3	35	49	C
Andosols											
T	TOP	306	5.8	4.0	7.5	2	114	187	3	0	C
T	SUB	356	6.0	4.5	8.2	0	82	266	8	0	C
Th	TOP	160	5.5	4.0	6.6	2	80	78	0	0	C
Th	SUB	204	5.9	4.5	7.1	0	60	144	0	0	C
Tm	TOP	48	6.1	5.2	7.5	0	6	41	1	0	C
Tm	SUB	60	6.3	5.0	8.2	0	4	52	4	0	C
To	TOP	38	5.8	4.2	7.4	0	13	24	1	0	C
To	SUB	29	6.3	4.6	7.8	0	7	18	4	0	C
Tv	TOP	60	6.1	4.6	7.4	0	15	44	1	0	C
Tv	SUB	63	6.2	4.6	7.0	0	11	52	0	0	C
Rankers											
U	TOP	14	5.6	4.3	6.5	0	7	7	0	0	C
U	SUB	2	4.8	4.5	6.5	0	1	1	0	0	C
Vertisols											
V	TOP	471	7.5	4.2	9.7	0	6	199	231	35	C
V	SUB	473	8.0	3.9	9.4	2	4	79	310	78	C
Vc	TOP	258	7.9	4.2	9.1	0	2	74	161	21	C
Vc	SUB	289	8.1	3.9	9.3	2	1	33	208	45	C
Vp	TOP	213	7.2	5.1	9.7	0	4	125	70	14	C
Vp	SUB	184	7.8	5.0	9.4	0	3	46	102	33	C

FAO unit	depth	N	Med.	Min.	Max.	pH_H2O <=4.0	4.4-5.5	5.6-7.3	7.3-8.5	8.5<	status
Planosols											
W	TOP	131	6.0	3.7	8.8	11	32	73	13	2	C
W	SUB	125	6.6	4.0	9.4	2	31	47	33	12	C
Wd	TOP	24	4.2	3.7	5.7	10	13	1	0	0	C
Wd	SUB	23	4.6	4.0	6.3	2	18	3	0	0	C
We	TOP	41	5.9	4.3	8.8	0	13	26	0	2	C
We	SUB	44	6.4	4.4	9.0	0	9	26	6	3	C
Wh	TOP	0	6.0	-	-	-	-	-	-	-	Z
Wh	SUB	0	7.0	-	-	-	-	-	-	-	Z
Wm	TOP	18	6.0	5.2	6.8	0	1	17	0	0	C
Wm	SUB	18	7.6	5.2	8.8	0	1	6	10	1	C
Ws	TOP	48	6.4	3.9	8.1	1	5	29	13	0	C
Ws	SUB	40	7.8	4.9	9.4	0	3	12	17	8	C
Wx	TOP	0	6.0	-	-	-	-	-	-	-	Z
Wx	SUB	0	7.0	-	-	-	-	-	-	-	Z
Xerosols											
X	TOP	240	7.6	4.5	9.0	0	7	80	134	19	C
X	SUB	204	7.8	5.1	9.6	0	5	47	109	43	C
Xh	TOP	38	8.0	5.9	8.9	0	0	7	24	7	C
Xh	SUB	30	8.0	5.5	9.1	0	1	2	22	5	C
Xk	TOP	39	7.9	7.2	9.0	0	0	3	31	5	C
Xk	SUB	26	8.3	7.2	9.6	0	0	2	13	11	C
Xl	TOP	146	7.3	4.5	8.9	0	7	67	67	5	C
Xl	SUB	131	7.8	5.1	9.4	0	4	40	64	23	C
Xy	TOP	17	7.9	7.3	8.9	0	0	3	12	2	C
Xy	SUB	17	7.8	7.0	9.1	0	0	3	10	4	C
Yermosols											
Y	TOP	130	7.9	4.5	10.0	0	6	22	93	9	C
Y	SUB	113	8.0	4.8	10.1	0	3	15	86	9	C
Yh	TOP	18	8.1	4.7	10.0	0	3	1	12	2	C
Yh	SUB	20	8.2	5.9	10.1	0	0	1	14	5	C
Yk	TOP	32	8.0	7.0	8.8	0	0	3	26	3	C
Yk	SUB	28	8.1	7.0	8.5	0	0	2	26	0	C
Yl	TOP	42	7.5	4.5	9.3	0	3	15	21	3	C
Yl	SUB	37	7.9	4.8	8.9	0	3	10	21	3	C
Yt	TOP	3	7.2	6.9	7.4	0	0	2	1	0	C
Yt	SUB	2	6.9	6.9	7.0	0	0	2	0	0	C
Yy	TOP	35	7.8	7.1	8.6	0	0	1	33	1	C
Yy	SUB	26	7.8	7.4	8.6	0	0	0	25	1	C
Solonchaks											
Z	TOP	166	8.2	6.3	10.6	0	0	20	100	46	C
Z	SUB	146	8.3	6.4	10.8	0	0	7	85	54	C
Zg	TOP	48	8.3	6.3	10.6	0	0	5	26	17	C
Zg	SUB	39	8.5	7.2	10.7	0	0	1	19	19	C
Zm	TOP	5	7.8	7.5	8.4	0	0	0	5	0	C
Zm	SUB	5	8.1	7.6	8.8	0	0	0	4	1	C
Zo	TOP	106	8.1	6.7	10.5	0	0	14	64	28	C
Zo	SUB	98	8.2	6.4	10.8	0	0	6	58	34	C
Zt	TOP	7	7.7	7.1	8.6	0	0	1	5	1	C
Zt	SUB	4	7.8	7.6	7.9	0	0	0	4	0	C

Notes:

* Status: C, computed median value; D, derived value (from 1st level units, all units except Histosols and Andosols), Z: derived value (median from related 2nd level units).
* Class intervals for pH(H_2O): (a) pH <= 4.0; (b) 4.0 <ph<= 5.5; (c) 5.5 <pH <= 7.3; (d) 7.3 <pH<= 8.5; (d) 8.5 <pH.
* Analysis: 1:1 to 1:5 soil:water dilution, saturated paste data are excluded from analyses.
* Depth intervals: (a) TOP is from 0 cm <= topdep< 30 cm and botdep < 50 cm; (b) SUB is from 30 cm <= topdep < 100 cm.

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