3 Soil Classification

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Abstract

In 2014 the 3rd Edition National Soil Map of Ireland was published at a resolution of 1:250,000, accompanied by an associated online soil information system (SIS) database. The 3rd Edition National Soil Map was developed using a combination of novel digital mapping techniques, traditional field survey methods, and historic soil survey detail. This produced for the first time, a consistent national level legend for Irish soils. Irish soil classification 2014 consists of a three-tiered taxonomy of 'Great Soil Group', 'Subgroup' and 'Series', ordered from the most general to the most specific. This chapter explains how soils are classified including the reference section, how to describe a soil profile, horizon definitions and soil diagnostic criteria. Finally, the correlation of the Irish SIS with World Reference Base (WRB) classification is described and the classification of urban soils using the WRB system.

Keywords

Soil classification • Diagnostic criteria • Great Soil Groups • Subgroups • Soil series • World Reference Base

3.1 Introduction

The launch of the Irish Soil Information System (SIS) in 2014 represented a major advancement in the availability of soil information at a national level in Ireland. A comprehensive inventory of soil data in Ireland compiled in 2007 highlighted that soil data coverage was incomplete in detail and extent (Daly and Fealy 2007), and that an updated soil map was necessary to satisfy a growing demand to meet sustainability targets (Creamer et al. 2014). The Irish SIS project was designed to satisfy this growing need, a key output of which was the development of the 3rd Edition National Soil Map of Ireland, a digital map at a resolution of 1:250,000 (Chap. 4). The Irish SIS combined novel digital mapping techniques with traditional field survey methods and historic soil survey detail, to establish a consistent national legend for Irish soils. A brief overview of the World Reference Base for Soil Resources (WRB) with specific attention to the correlation of the Irish SIS with the WRB classification system is also presented.

As described in Chap. 2, soil formation and development depends upon the interactions of several factors. Soil classification within the Irish SIS recognises these soil forming factors and processes, morphology and soil geographic approaches which have been complemented with laboratory data for verification (Simo et al. 2015). The heterogeneity of soil insists that similar members are grouped together so that the great number of soils, which vary from one another in different degrees of contrast, can be clustered into progressively higher categories (USDA 1960). Thus, soil classification is the process of grouping soils together where a similar range of chemical, physical and biological properties

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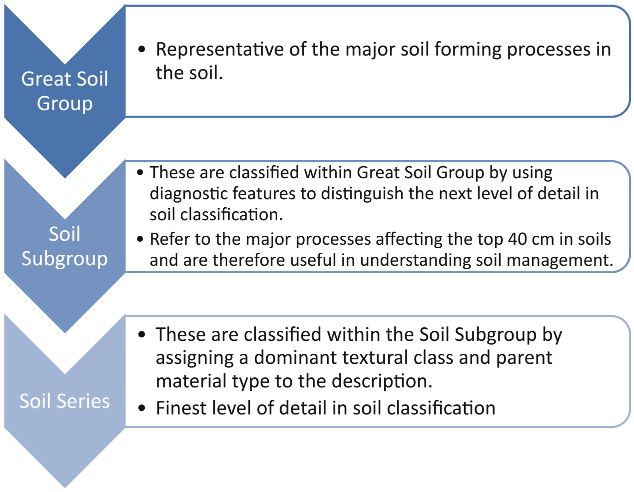

Fig. 3.1 Three-tiers of soil taxonomy in the 2014 Irish soil classification

have been observed, into units that can be geo-referenced and mapped. The Irish SIS consists of a three-tiered taxonomy of 'Great Soil Group', 'Subgroup' and 'Series', ordered from the most general to the most specific (Fig. 3.1).

3.2 Reference Section

The reference section refers to the vertical section of the soil profile which is described and classified. Within this section, diagnostic horizons are identified following set principles outlined in the Irish SIS handbook. The depth or thickness of this section varies depending upon the soil parent material. In Irish soil classification, four main reference section depths are recognised:

1. Soils in peat have a reference section that extends from 40 to 80 cm with organic material deeper than 80 cm (Fig. 3.2). Utilising a thickness of 40 cm or more of peat

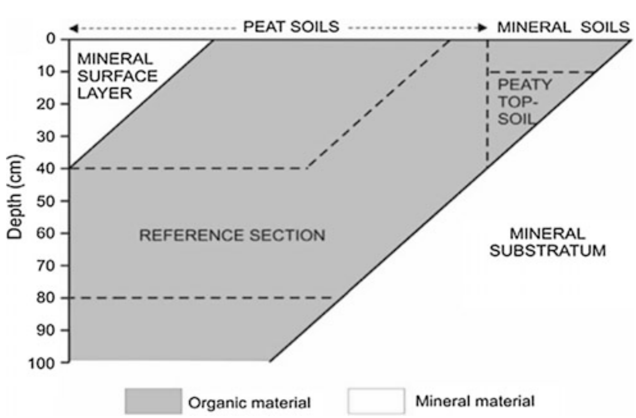

Fig. 3.2 Reference section for peat soils (from Simo et al. 2014, based upon Clayden and Hollis 1984 p. 13)

to classify peat soils is consistent with the WRB definition of Histosol (IUSS Working Group WRB 2006). These soils are composed of organic material largely derived of partially decomposed plant remains that accumulated under waterlogged conditions, either formed in situ or as constituents of sub-aquatic sediments such as organic lake muds (Avery 1980).

In peat soil, the mineral fraction has little textural significance as peats are mostly composed of organic materials. Soils with more than 50% organic matter are defined as peats. Soils with less than 50% but greater than 20% organic matter and with 50% or more sand content in the mineral fraction are defined as Sandy Peat, or with less than 50% sand content defined as Loamy Peat. Other criteria for differentiation of soils in peat of less than 50% organic matter: Soils with organic carbon (OC) <20% (calculated by organic carbon analysis), two categories are distinguished; soils with more than 12% OC and more than 50% Sand, they are defined as Peaty sand; and soil with OC >14.5% and amount of clay $\geq$ 50%, defined as Peaty loam.

2. **Histic Organic soils over bedrock** mainly consist of organic material over a layer of coherent bedrock or skeletal products of weathering. These soils extend from the organic soil surface to the upper surface of this bedrock/skeletal layer, whichever is at the shallowest depth (30 cm). The peaty (> 20% OC) O horizon must have a thickness of 7.5 cm or more.
3. **Mineral soils over bedrock or lithoskeletal substrate** are comprised of mineral material overlying bedrock or skeletal weathered bedrock fragments. This includes two subtypes (Clayden and Hollis 1984): Firstly, where the surface layer is no greater than 30 cm thick, typically occurring as Rendzina or Lithosol soils. Secondly, where the profile depth is greater than 30 cm but bedrock occurs within 80 cm (Simo et al. 2014).
4. **All other substrates**, which includes any mineral soils comprised in thick drift. In general, soil material must be at least 80 cm thick. These substrates are mostly glacial till or fluvio-glacial deposits and recent alluvium.

3.3 Describing a Soil Profile

Part of the process of describing the soil profile includes a site description. Local landscape description is an important part of the soil classification process. On arrival GPS locational data and the principal landscape features should be recorded, such as relief, topography, aspect and land use (Fig. 3.3). Once the profile pit is dug to a depth of approximately 1.2 m, the profile face must be cleared and photographed, along with recording the parent material. Thereafter, each horizon should be described in detail with characteristics of field estimated

Representative Profile Pit Card

Reference No	Date	
Map Sheet	Observers	- -

Latitude (N/S)		Longitude (E/W)	
Grid Reference (N/S)		Grid Reference (E/W)	
Local Location			
Farmer's name			
Photo	from	to	Status

Sub Group	Series
Definition	

Landform	Slope Position	Sl deg	Aspect	Form	Elevation
Land Use Type	LU Class	Human			
Vegetation Class	VU species	WT	Weather		
Primary Substrate Type/Subgroup	Secondary Substrate Type/Subgroup				
Rock Outcrops	Surface Stoniness				

NOTES

HORIZON number	Depth	to	Horizon Designation
BARCODE composite	BARCODE bulk density		

PSC	Humose	Clay %	PS mod	PEAT Von Post	Fibre

COLOUR	Matrix				FIELD pH
Mottle 1	Abundance	Size	Contrast	Sharpness	CARBONATES
Mottle 2	Abundance	Size	Contrast	Sharpness	SOIL WATER

STONES	Size	Abund	Shape	Lithology	ROOTS	Size	Abund

COATS/	Type1	Abund	Contrast	Continuity	CONSISTENCE dry	PLASTICITY
NODULES	Type2	Abund	Contrast	Continuity	CONSISTENCE moist	STICKINESS

STRUCTURE	Grade	Type	Size	Strength	CEMENT/COMPACT	Nature	Degree
VOIDS (POROSITY)	Size	Abund	Fissures (Size)	MACROPORES	Size		
BOUNDARY	Distinctness	Shape	Packing density				

NOTES

Fig. 3.3 Profile description card to record the site description and horizon detail for each horizon. During the SIS campaign a field tablet with a supporting database and interface was used to record data directly in the field

Table 3.1 Sampling of horizons in Irish SIS (Creamer et al. 2014)

Chemical properties (2 kg composite fresh soil from each horizon)	pH (in H_20 and $CaCl_2$) Total: C, N Organic carbon Organic matter content (Loss on ignition) Cation exchange capacity (CEC) Base saturation (BS) Fe/Al (oxalate extraction)
Physical properties	Bulk density: three per horizon reported as average value (cm^3) with standard deviation (σ) (Fig. 3.4). Texture

texture, structure, colour, carbonates, stone content and type, root content and depth and the presence of biota recorded (Creamer et al. 2014).

In relation to analysing soil profile pits, along with the classification criteria described, a suite of measurements were analysed at horizon level (Table 3.1) to provide a more complete description of the soil profile.

Figure 3.4 (left) shows an open profile pit with three bulk density rings taken per horizon. Final bulk density values are recorded on a horizon basis and reported as an average value (cm^3) with standard deviation (σ).

3.4 Horizon Definitions

When characterising or classifying soil type, it is essential to define the differing layers (horizons) found within the soil profile. This characterisation is done by defining certain characteristics such as structure, colour, porosity, mottling, textural changes, pH, etc. These characteristics are then used to classify genetic horizons. The classification of soils at Subgroup level requires that the various horizons of the soil profile are described and defined. Horizon definitions within the Irish SIS are fully described in the field handbook by Simo et al. (2014). Overall, there are three main horizons, A, B and C that occur in a majority of soil profiles as shown in Fig. 3.5. The A and B horizons constitute the 'true soil' whilst the C horizon refers to parent material. Some soils lack a B horizon and are said to have AC profiles. On other soils, organic layers (O horizons) may overlie the mineral horizons. Underlying rock is indicated by the symbol R.

Organic horizons

- Peaty O horizons accumulate under wet conditions. They are saturated with water for at least 30 consecutive days in most years, or have been artificially drained, and include fibrous, semi-fibrous and amorphous peat. Sub-horizons include: Of, Omf, Oh, Op.

Fig. 3.4 Three bulk density rings per horizon as a physical soil measurement shown on left, method for bulk density measurements shown on right (Photo: Jeremy Emmet-Booth)

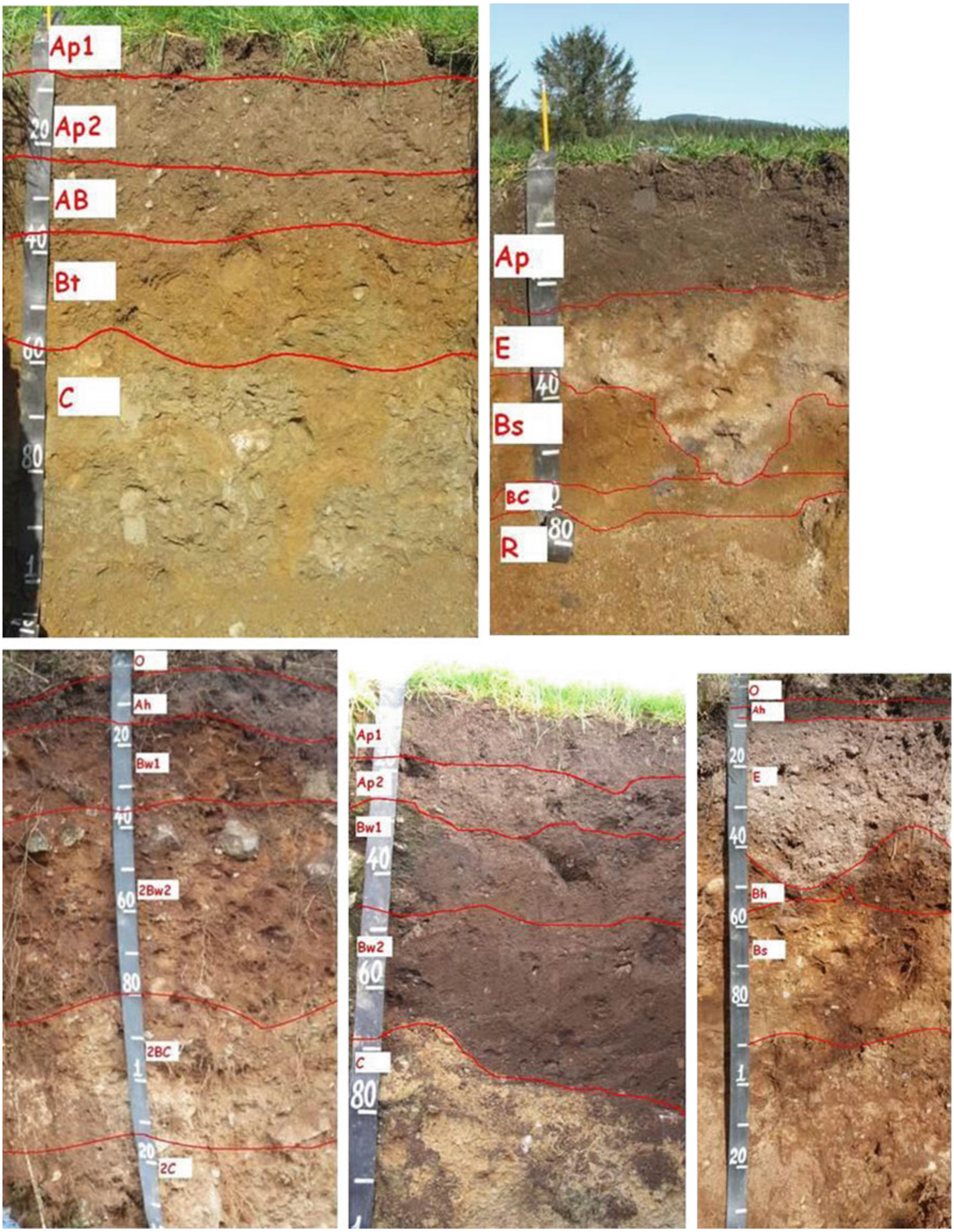

Fig. 3.5 Sample soil profiles annotated with soil horizon designations. *Source* Irish Soil Information System

- L horizon represents fresh litter deposited during the previous annual cycle. It is normally loose and the original plant structures are little altered.
- F, H are organic horizons originating as litter deposited or accumulated at the surface and seldom saturated with water for more than a month at a time. The F has partly

Table 3.2 Suffix and definition

Suffix	Property[a]	Horizon identifier
f		The presence of an Ironpan
g	Gleying	Intense reduction of iron or reduction due to seasonal or continuous waterlogging. A greyish colour due to wetness can be found and oxidised Fe and Mn mottles and/or coatings are concentrated on ped surfaces
h	Humic	Considerably more organic matter than mineral matter, with thickness over 15 or 10–15 cm if over bedrock
k	Calcareous	Calcareous in nature within 40 cm of surface having formed in calcareous parent material, with >2% $CaCO_3$
p	Ploughing	Evidence of disturbance by cultivation
r	Regolith	Loose superficial material covering solid rock
s	Spodic	Enrichment of organic matter complexed with Fe and Al due to illuviation and/or biochemical weathering in situ
t	Argillic	Accumulation of translocated clay.
u	Unconsolidated	Unconsolidated, normally apedal but may show stratification
w	Weathering	Evidence of alteration
x	Fragic	Properties include firmness, brittleness with a high bulk density reflecting a compact but uncemented nature

[a]Where suffix letter appears capitalised indicates a dominance of that characteristic

decomposed or comminuted litter, remaining from earlier years, in which some of the original plant structures are visible to the naked eye. The H has well decomposed litter, often mixed with mineral matter, in which the original plant structures cannot be seen.

Mineral horizons

- The A horizon refers to the mineral horizon formed at or near the surface. An A horizon is characterised by incorporated humified organic matter, or by evidence of cultivation, or both. The incorporation of organic matter is presumed to be due to biological activity or artificial mixing. Horizon designations include: Ah, Ap, Ahg, Apg, AB.
- The E horizon is a subsurface mineral horizon that contains less organic matter and/or dithionite-extractable iron and/or silicate clay than the immediately underlying horizon, presumably as a result of loss or washing out of one or more of these constituents.
- The B horizon is the mineral subsurface horizon, without rock structure characterised either by illuviation or by an alteration of original material such as the solution and removal of carbonates. Horizon designations that occur include: Bf, Bg, Bh, Bs, Bt, Btg, Bw, Bx, Bk, BC.
- The C horizon is usually unconsolidated or a weakly consolidated mineral horizon that retains soil structure or otherwise lacks the properties of the overlying horizons. C horizons may have been modified by gleying or by an accumulation of carbonates or soluble salts or they may have developed brittleness and associated properties of fragipans. Horizon designations include: Cu, Cr, Ck, Cg.

Many soils are subdivided on the basis of a significant difference within the main horizons. These differences are identified by the horizon designation accompanied by a suffix identifier (Table 3.2). Where lithological discontinuity occurs and two different geologic parent materials are present, the number '2' is placed in front of the horizon symbol for horizons developed in the second parent material.

3.4.1 *Diagnostic Criteria*

Table 3.3 describes the criteria for the diagnostic features included in the Irish SIS for the classification of soils at Subgroup level.

3.5 Classification of Great Soil Groups

Great Soil Groups represent the most general soil classification unit in the Irish SIS. Great Soil Groups are organised based upon the dominant soil forming factors. Soils within Great Soil Groups have common characteristics and soil forming conditions; they are developed under the influence of environmental factors (vegetation and climate) active over a considerable geographic range and have one or more Subgroups of soil. Soils occurring in a Great Soil Groups have the same arrangement and degree of expression of horizons in the soil profile. In Ireland, 11 Great Soil Groups have been identified and are coded 01–11: (01) Ombrotrophic Peat Soils; (02) Mineratrophic Peat Soils; (03) Rendzina; (04) Lithosols; (05) Alluvial Soils;

Table 3.3 Diagnostic features to classify soil subgroup

0 None	There are no distinguishing characteristics associated with this feature
1 Histic	This is a peaty (>20% OC) (O) horizon of ≥ 7.5 cm thickness or more, overlying mineral soil or rock material. It generally occurs at the surface or beneath a thin layer of more or less decomposed litter (L, F). This diagnostic horizon is conceptually equivalent to the histic horizon in WRB (IUSS Working Group WRB 2006) but is allowed to be thinner than the ≥ 10 cm specified by the WRB
2 Gleyic	This feature occurs in soils affected by seasonal or continuous waterlogging. The presence of Fe and manganese (Mn) concretions and/or nodules of grey colouring due to the continuous presence of a water table, this can be indicative of wetness. A gleyed subsurface horizon has greyish colours caused by the reduction of Fe and Mn in the lower part of the profile and/or inside the peds, with oxidised Fe and Mn mottles and/or coatings being concentrated on ped surfaces Requirements: 1. Qualifies as Eag, Eg, Bg, Btg, BCg, Cg or CG within 80 cm depth, and lacks a slowly permeable sub-surface layer; and 2. At least 5 cm thick and extends below 30 cm depth; and 3. In general, the lower subsoil horizons will have grey matrix colours: a. Hue 7.5YR chroma = 1; b. Hue 10YR or yellower chroma $\leq$ 2; or c. Greyish (Hue N, GY), greenish (Hue GY,G) and bluish (Hue BG, B) hues
3 Stagnic	This is a subsurface horizon (within 40 cm) that is at least 15 cm thick, which displays evidence of reduced Fe and Mn as a result of a perched water table, forming a significant barrier to water movement for a period long enough to allow reducing conditions to occur. This soil reflects mottling where the surfaces of the peds (or parts of the soil matrix) are lighter (at least one Munsell value unit more) and paler (at least one chroma unit less), and the interiors of the peds (or parts of the soil matrix) are more reddish (at least one hue unit) and brighter (at least one chroma unit more) than the non-redoximorphic parts of the layer (IUSS Working Group WRB 2006). These soils tend to have slowly permeable subsurface horizons, i.e. as a result of fragipan characteristics
4 Fe–Ac	This is a B horizon in which amorphous materials containing Al and/or Fe that have accumulated, either by illuviation or by biochemical weathering in situ. It meets the following requirements (An Foras Talúntais unpublished): 1. Qualifies as an Iron-pan horizon or 2. The moist chroma is greater than 3, or the value is ≤ 3; and 3. Starts within 120 cm depth; underlies an E, A, H or O horizon, and extends below 15 cm depth, excluding fresh or partially decomposed litter (L, F); or 4. The horizon must be at least 10 cm thick if there is no overlying albic E horizon and it consists only of a Bs horizon; at least 2.5 cm thick if it consists only of a Bh horizon below an albic E horizon. This diagnostic horizon is similarly defined to the spodic horizon (FAO 2006)
5 Calcareous	Soils in which a calcareous horizon is present within 40 cm of the surface, have a calcareous B horizon and are formed in calcareous parent materials. Calcareous nature is defined as > 2% $CaCO_3$, where a visible effervescence is displayed when applying a few drops of 10% Hydrochloric Acid
6 Humose	This is a soil which contains an A horizon with significantly more organic matter, than mineral matter. It can occur as a sequence of H or Oh and Ah horizons that meet the following requirements over a thickness of more than 15 cm or 10–15 cm if directly over bedrock (R or Cr): 1. Moist rubbed colour with value and chroma of 3 or less 2. Humose or partly humose and partly organic (<7.5 cm thick) As a guideline in the field, humose soil materials generally have moist rubbed colour value/chroma of 3/2 but in addition the soil should feel soapy and slippery due to the organic matter, the presence of which is more difficult to detect in silty soils because organic and silty materials have a similar feel. The presence of a humose topsoil usually qualifies as a mollic horizon if it has high base saturation (FAO 2006) or umbric horizon in WRB if it is base depleted (IUSS Working Group WRB 2006). In podzols, humic refers to the presence of a Bh horizon
7 Drained	Drained soils are primarily where human activity has altered the drainage status of the soil from poorly drained to imperfectly to moderately drained status. In organic soils this activity results in an earthy soil in peaty surface layers (Op or Oh). These need to be at least 20 cm thick and contain less than 15% w/w visible plant remains (fibres). It sometimes overlies an organic subsurface horizon and usually has a distinct granular or subangular blocky structure
8 Cut-over	Cut-over Ombrotrophic Peat Soils have had the surface peat removed by hand cutting methods but the peat thickness still meets the criteria for peat soils
9 Anthropic	This diagnostic horizon corresponds to the thick A1 horizon of De Bakker and Schelling (1966), and includes Hortic, Plaggic and Terric horizons in WRB (IUSS Working Group WRB 2006). Most commonly Anthropic features are used to describe a terric horizon (from Latin terra, earth) which is a human-induced surface horizon >40 cm thick. These horizons develop through the addition of earthy manures, compost, beach sands, calcareous sands and shells or mud over a long period time. It builds up gradually and may contain stones, randomly sorted and distributed. It commonly contains artefacts such as pottery fragments, cultural debris and refuse, which are typically very small (<1 cm in diameter) much abraded and occupy <20% volume of the horizon. This horizon may also include soil material that has been imported to a site causing a significant alteration of the surface horizon, such as soil inversion

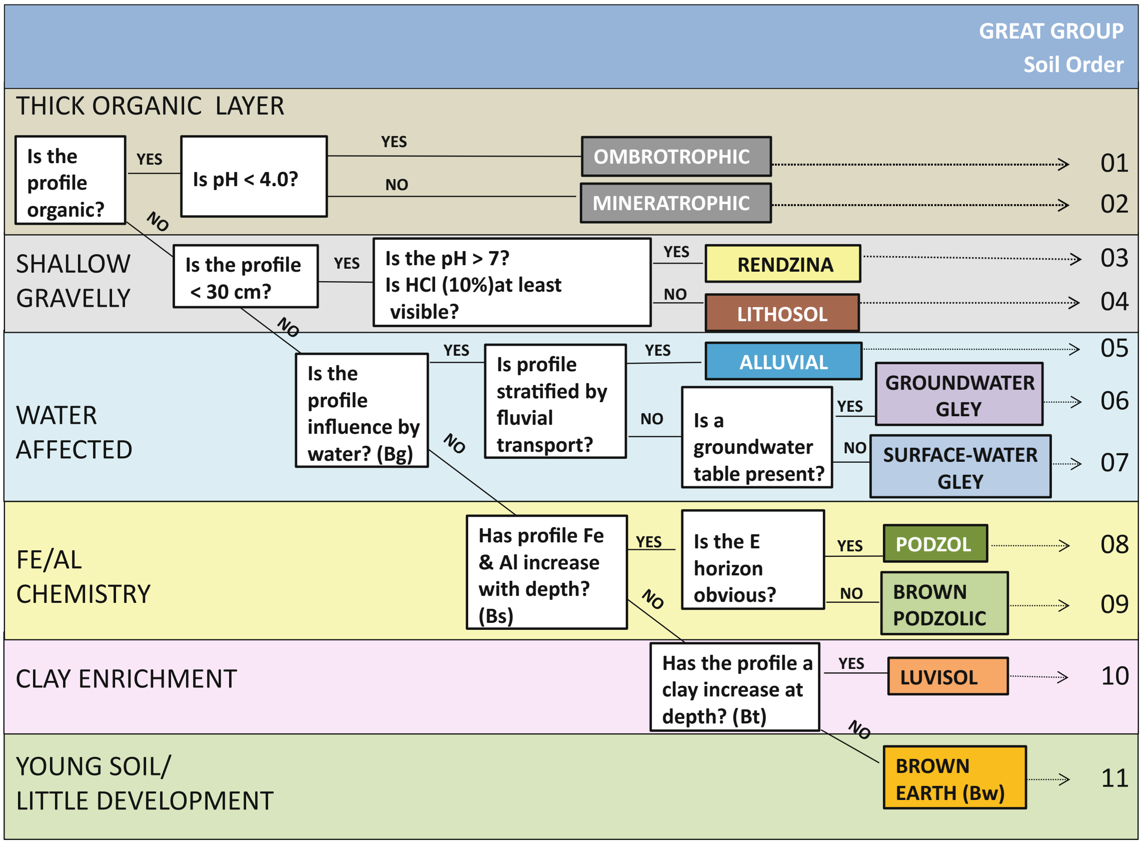

Fig. 3.6 Key to determine Great Soil Group classification based upon Irish SIS Classification 2014

(06) Groundwater Gleys; (07) Surface-water Gleys; (08) Podzols; (09) Brown Podzolic; (10) Luvisols and (11) Brown Earths. The following key allows a simplified determination of Great Soil Group within the Irish SIS by following a quick yes/no system that is applied from the top to the bottom. The most distinguishing features are at the top of the key, and Brown Earths are at the bottom representing the group with the fewest distinguishing features (Fig. 3.6).

This key is based upon the following principles, with criteria synthesised in Table 3.4:

- Organic soils are first differentiated from mineral soils and are further defined on the basis of whether they are rain-fed (Ombrotrophic peat) or groundwater-fed systems (Minerotrophic peat). If pH is <4 they are Ombrotrophic. If pH >4 they are classified as Mineratrophic peat soils.
- Next shallow soils (<30 cm) with a severe limitation to rooting are identified as Lithosol or Rendzina soils. If the soil pH is >7, or if the presence of calcium carbonate ($CaCO_3$) is induced by a hydrochloric acid (HCl) (10%) reaction these soils are classified as Rendzina soils.

Table 3.4 Sequencing of Great Soil Groups (Simo et al. 2014)

Criteria	Code	Great Soil Group
Soils with thick organic layers	1	Ombrotrophic Peat
	2	Minerotrophic Peat
Shallow or extremely gravelly soils (<30 cm)	3	Rendzina
	4	Lithosol
Soils influenced by water	5	Alluvial
Within 40 cm	6	Groundwater Gley
	7	Surface-water Gley
Soils affected by Fe/Al chemistry increase	8	Podzol
	9	Brown podzolic
Soils with clay enriched subsoil	10	Luvisols
Relatively young or soils with little profile development	11	Brown Earth

- Thirdly soils that are influenced by water are identified due to the presence of mottling in the soil profile. If the profile shows stratification associated with fluvial transport and deposition, these soils are classified as Alluvial soils. If there is no evidence of Alluvial bands, the profile is checked for a groundwater influence. This should be clearly observed within the surface 40 cm. If present, the profile will exhibit a grey uniform colour throughout the profile and these soils are classified as Groundwater Gleys. These are typically influenced by location and are often found near rivers or inter-drumlin hollows where the water table is high. If no groundwater influence is found, these soils are classified as Surface-water Gleys which are poorly drained due to presence of a slowly permeable subsurface layer.

- If the profile has not been influenced by water, the profile is next checked for iron (Fe) and/or aluminium (Al) chemistry. Where Fe and Al have played a major role in the soil formation, soils are classified as Podzols and Brown Podzolics. Where an obvious E horizon exists, indicating a zone of eluviation is present, these soils are classified as Podzols. This is evidenced by the presence of a bleached white sandy layer. Soils where no E horizon is evident, but where clear Fe/Al accumulation has occurred in the Bs horizon are defined as Brown Podzolics.
- Step five, soils with clay illuviation from surface and/or sub-surface horizons to lower down the profile are classified as Luvisols. These soils have an increase of clay in the lower horizon by 20% (presence of a Bt horizon).
- Finally, Brown Earths which are relatively young soils or soils with limited profile development are identified and represent the group with no clear distinguishing features.

Soils vary due to a suite of soil forming factors and processes, including topography (see Chap. 2). As a result, the catena sequence of soils varies from hilltop to valley floor. As the Irish SIS considers these soil forming factors and processes, a generalised description of the soil catena sequence can be presented (Fig. 3.7) with the 11 Great Soil Groups of Ireland described across a landscape position.

3.6 Classification of Soil Subgroups

The second level of classification in Irish SIS is the Soil Subgroup. Altogether, the Irish SIS contains 67 Subgroups, based upon the diagnostic features found within the 11 Great Soil Groups. The character of the various horizons in the soil profile, reflect the influential processes of soil formation that represent the true characteristics of a soil that are important for its use and management. Diagnostic features are soil properties that describe soil characteristics and are used to classify the Soil Subgroup.

Altogether nine main diagnostic features are included in the Irish SIS, coded 1–9 (Fig. 3.8). 0 is also included in the classification key and indicates that there are no additional distinguishing characteristics present. The Irish SIS has developed a key based upon the following principles:

1. The first number in the code refers to the Great Group (01–11) following the key system (Fig. 3.6).
2. The second number is the dominant diagnostic feature (Fig. 3.8) code (0–9).
3. The third number is the secondary diagnostic feature code (0–9) (Fig. 3.8).

The nomenclature at Subgroup level provides the most information on the soil processes, as Subgroups are named on the basis of the most important features that occur in the reference section to a maximum of two, described as

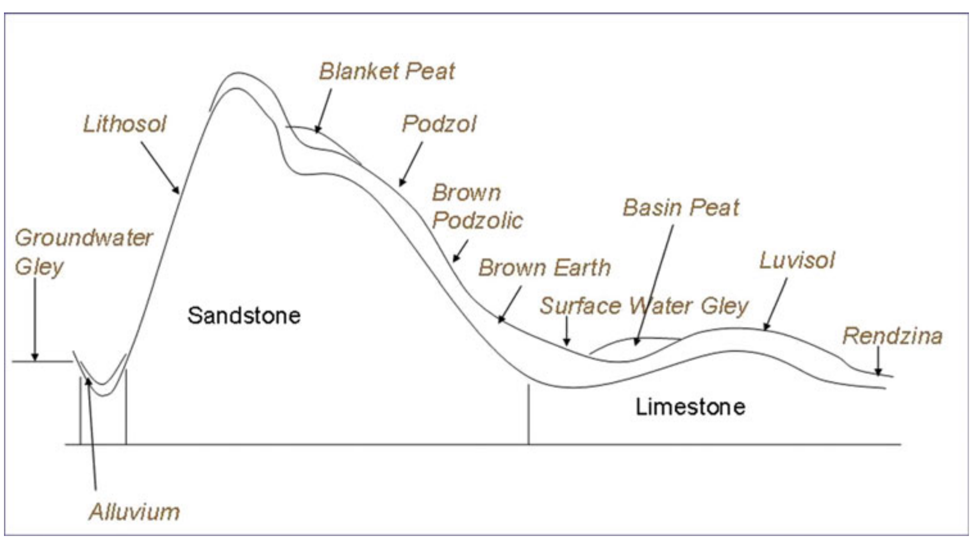

Fig. 3.7 Great Soil Groups described across a landscape position (Simo et al. 2014)

Fig. 3.8 Key codes applied according to the subgroups and diagnostic features

Diagnostic Feature		None	Histic	Gleyic	Stagnic	Iron-pan	Calcareous	Humose	Drain	Cut	Anthropic
Subgroup	Code	0	1	2	3	4	5	6	7	8	9
Ombrotrophic Peat	01		01.1.0						01.7.0	01.8.0	01.9.0
Mineratrophic Peat	02		02.1.0						02.7.0	02.8.0	
Rendzina	03	03.0.0	03.1.0					03.6.0			
Lithosol	04	04.0.0	04.1.0					04.6.0			
Alluvial	05	05.0.0	05.1.0				05.5.0 05.5.1 05.5.6	05.6.0	05.7.0 05.7.2 05.7.6		
Groundwater Gley	06	06.0.0	06.1.0		06.3.0 06.3.6		06.5.0 06.5.1 06.5.6	06.6.0			06.9.0
Surface-water Gley	07	07.0.0						07.6.0			07.9.0
Podzol (Fe-Ac)	08	08.0.0		08.2.0	08.3.0	08.4.3		08.6.0			08.9.0
Brown Podzolic	09	09.0.0		09.2.0	09.3.0 09.3.6			09.6.0			09.9.0
Luvisol	10	10.0.0		10.2.0 10.2.6	10.3.0 10.3.6			10.6.0			10.9.0
Brown Earth	11	11.0.0		11.2.0 11.2.6	11.3.0 11.3.6		11.5.0 11.5.3 11.5.6 11.5.9	11.6.0			11.9.0 11.9.2 11.9.3 11.9.6

additional features to the Great Soil Group. For example, a Humic Calcareous Brown Earth is coded as 11.5.6 (Fig. 3.8) where 11 indicates the Great Group; the soil is predominantly calcareous (within 40 cm) indicated by a five, 11.5 and finally, the soil also has a humose surface horizon represented by a six, therefore: 11.5.6. Figure 3.8 shows the Subgroups that exist within Irish SIS.

3.7 Classification of Soil Series

Soil Series is the final level of classification and represents the most specific category in the taxonomy. In Ireland, of the final 213 Soil Series classified, 73 originated and were described by the AFT soil survey. Series are defined on the basis of the following hierarchy; Great Soil Group, Soil Subgroup, texture and parent material. Series names are derived from the place names, such as town lands, from where the soil was first defined or where it was best expressed. Soil Series are identified by a unique code made by concatenating the Subgroup code with a code based upon the series name; for example, 'Ballylanders' is a Typical Brown Earth (1100) and has a map code 'BY', hence the unique full series code is '1100BY' (Simo et al. 2013).

Texture refers to the relative proportions of the various sized particles in the mineral fraction of the soil, specifically the sand, silt and clay less than 2 mm in diameter (Gardiner and Radford 1980). Texture is described at horizon level. Soil texture is one of the most important physical characteristics of the soil due to its influence on soil properties, such as moisture retention. The Irish SIS applied the particle-size distributions as adopted by USDA (Fig. 3.9) to maintain consistency with earlier soil survey work carried out by AFT. Particle sizes are described as follows: sand (2 mm–50 picometre (pm)), silt (50–2 pm), and clay (<2 pm) sized particles.

Overall soil profile texture: Four broad particle-size groupings are defined for generalising the overall texture of the reference section; sandy (Sy), loamy (Ly), silty

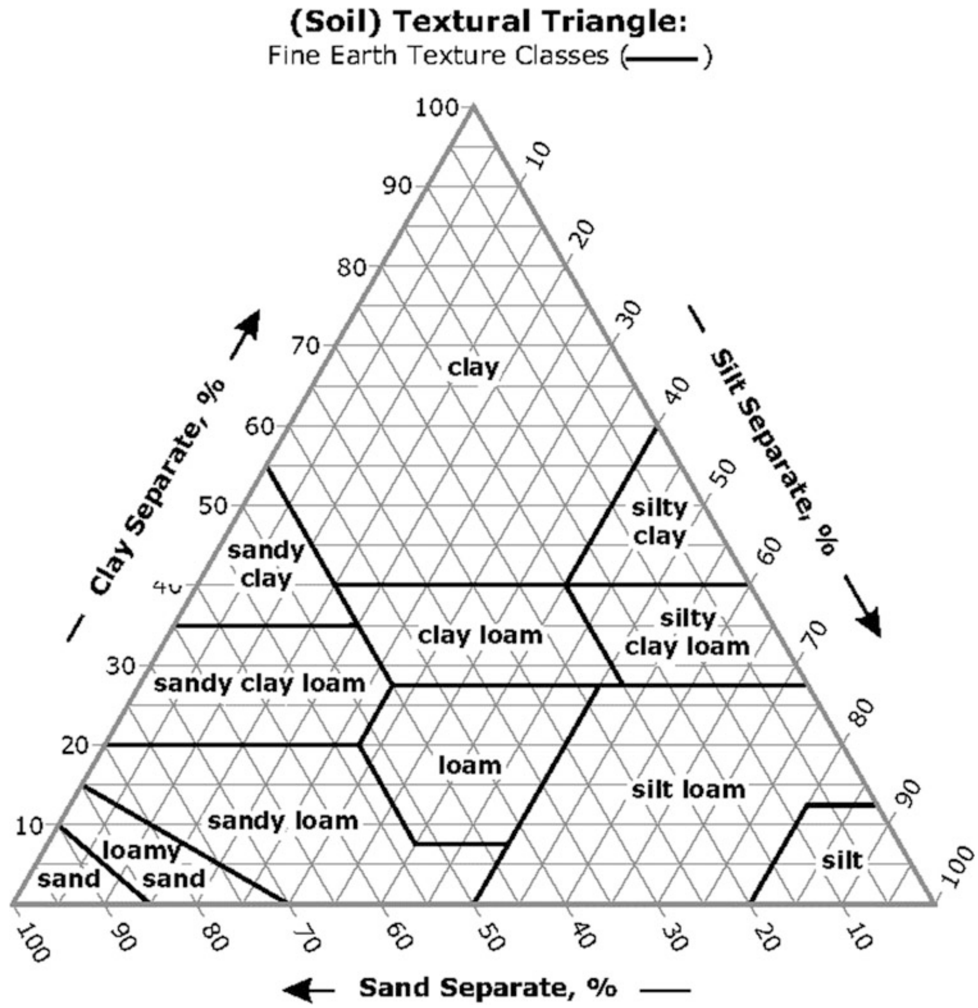

Fig. 3.9 Chart with percentages of clay (<0.002 mm) silt (0.002–0.05 mm) and sand (0.05–2.0 mm) in the basic soil texutre classes (Soil Survey Staff 1993)

(Zy) and clayey (Cey). When describing the total profile, as opposed to individual horizons, texture is described on the basis of particle size classes (Fig. 3.10). For agriculturally important soils, the loamy and silty groups are further subdivided into coarse and fine categories. To define the soil as either coarse (cLy) or fine loamy (fLy) the dominant texture within 80 cm should be used to define the broad textural class. The following procedures are applied (Jones et al. 2014):

1. if topsoil ~40 cm thick cLy over fLy, classify soil as cLy
2. if topsoil ~40 cm thick fLy over cLy, classify soil as fLy
3. if topsoil <40 cm thick fLy over cLy, classify soil as cLy
4. if topsoil <40 cm thick cLy over fLy, classify soil as fLy

In the Podzol and Lithosol Great Soil Groups, no distinction is made between coarse and fine loamy and Soil Series are described as Sandy, Loamy or Clayey (in Lithosols only).

Parent material is also used to define the Soil Series unit. Substrates in Ireland occur in five different states; peat, bedrock, drift, alluvium and anthropogenic (Table 3.5).

Peat is a biogenic deposit having developed in the post-glacial period of the last 10,000 years. Three main peat formations are recognised in Ireland (1) raised bogs of the Central Plain; (2) blanket bogs of the western seaboard and upland regions and (3) fen peat. Their genesis has been influenced by drainage, climate, hydrology, geomorphology, nutrient status and glacial geology but over time, these deposits have also been altered by man's activities.

Bedrock is the hard rock beneath surface materials such as soil and gravels. These soils comprise mineral material overlying a layer of coherent bedrock, or skeletal weathered bedrock fragments (that are at least 15 cm thick and begins above and extends below 80 cm depth). Where possible, effort to distinguish between bedrock and skeletal substrates should be made.

Drifts, the third substrate group, are composed mostly of Quaternary deposits including glacially-derived tills and fluvioglacial deposits and recent alluvium. The main classes

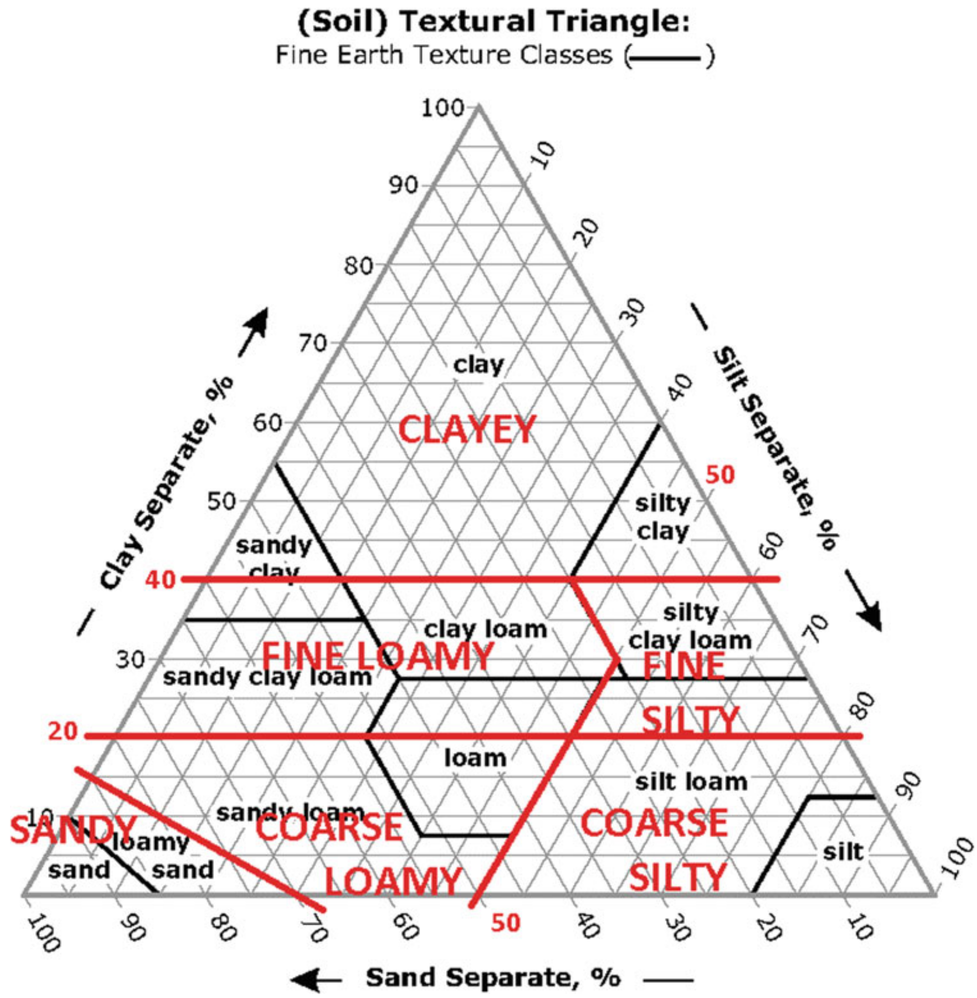

Fig. 3.10 Soil particle-size classes and broad groups for Soil Series definition (Jones et al. 2014) used in Irish soil classification 2014

of drift in Ireland found are: (1) drift with siliceous stones with deposits dominated by sandstone, slate, shale or chert stones. Soils in this substrate are usually non-calcareous to at least 120 cm; (2) drift with limestones that have calcareous material within 80 cm depth, or a non-calcareous B horizon within 80 cm but that passes conformable within 120 cm into calcareous material; (3) drift with igenous and metamorphic stones where these constitute the dominant local lithology and, (4) stoneless drift soils.

Alluvium substrate are soils that include all thick drifts in which loamy or clayey marine, river, or lacustrine sediments of recent age extend below 30 cm depth (Avery 1980) of which three types are used to define Soil Series; river alluvium, marine/estuarine alluvium and lake marl. However, the distinction between each type is not always clear because intrinsic properties such as structure, porosity, pH, $CaCO_3$ content, exchangeable cations and colour do not provide a consistent means of identification.

3.8 Correlation of Irish SIS to World Reference Base

Global population growth, land degradation and climate change, along with the interdependence of countries for the supply of food and agricultural produce, prompted the need for a global harmonised soil information system. On this basis the Food and Agriculture Organization of the United Nations (FAO) called on the active participation of the soil community to come together to develop a framework for the harmonisation of existing soil classification systems (IUSS Working Group WRB 2006). The first meetings were held in 1980 and 1981, hosted by the Poushkarov Institute of Soil Science and Yield Programming in Sofia, Bulgaria. At the first meeting it was decided to launch a programme to develop an International Reference Base for Soil Classification (IRB). At the second meeting, the general principles

Table 3.5 Substrate types used to define soil series in Ireland (Simo et al. 2014)

State	Substrate type	Materials
Peat	Blanket and Raised bog, fen cutover, industrial	
Bedrock	Basic igenous	Basalt, gabbro
	Acid igenous	Granite, rhyolite
	Limestone	Limestone
	Sandstone	Old Red Sandstone, millstone grit, quartzite, chert
	Shale/slate	Shale, slate, calcareous shale
	Sandstone and shales	Interbedded sandstone and shales Mica schist
	Gneiss and schist	
Drift (Till or fluvioglacial sediments)	With siliceous stones	Sandstones, shale, slate, quartzite, chert
	With limestones	Limestone
	With igenous and metamorphic stones	Basalt, gabbro, granite, gneiss, schist, aeolian, glaciolacustrine
	Stoneless Non-calcareous gravels Calcareous gravels	
Alluvium	River Estuarine Marine Lake marl	
Anthropogenic	Made ground	

of the joint programme towards the development of the IRB were defined (IUSS Working Group WRB 2006). In 1992, the IRB was renamed the World Reference Base (WRB), with the working group established at the 15th Congress of ISSS. The work culminated in the release of the first edition of the WRB for soil resources at the 16th World Congress of Soil Science at Montpellier in 1998. A second edition was subsequently released at the 18th World Congress at Philadelphia in 2006. The first edition comprised of 30 Reference Soil Groups (RSGs) with the second edition including 32 RSGs. Following a period of eight years, and an intensive worldwide testing and data collection effort, the third edition was launched in 2015 to reflect new updates and the earlier drafts and editions of the WRB (IUSS Working Group WRB 2015).

The development and revision of the publication of the WRB for soil resources has greatly contributed to a better understanding of soil science and has been used by the European Commission as the basis for harmonised assessment for the European Union and beyond. Many countries have adopted the WRB as a higher level to their national soil classification system (Reidy et al. 2014). The WRB was not designed as a national classification system but rather to serve as a mechanism for harmonisation to facilitate communication at an international level.

In the Irish SIS Final Technical Report 8, Reidy et al. (2014) describe the correlation of the Irish soil classification system to the WRB 2006 system. During the SIS field campaign 225 soil pits were described in detail with samples analysed to 1 m depth. The description and the associated analytical data were completed with consideration of correlation to the WRB system (Reidy et al. 2014). Within WRB, two categorical levels are defined: the 1st level contains the 32 RSGs with groups of soils based upon dominant identifiers such as soil forming factors or processes that indicate the soil condition. The RSG represent all major regions of the world. The 2nd level includes prefix and suffix qualifiers that are added to the RSG to allow precise characterisation and classification of individual soil profiles (Reidy et al. 2014). Within WRB the classification of soils is based on soil properties defined in terms of diagnostic horizons, properties and materials that take into account their relationship with soil forming processes. Diagnostic features are then included that are of significance to soil management

Table 3.6 Soil great group code and soil group in Irish classification and correlation to the WRB (Reference Soil Group) from Reidy et al. (2014) with dominant WRB reference group in bold

Soil group code	Soil group Irish classification	Reference soil group WRB
01	Ombrotrophic Peat	**Histosol (Ombric)**
02	Minerotrophic Peat	**Histosol (Rheic)**
03	Rendzina	**Regosol (Calcaric), Phaeozem (Calcaric)**
04	Lithosols	**Leptosol**, Histosol, Regosol, Cambisol
05	Alluvial	**Fluvisol**, Cambisol, Gleysol, Regosol, Stagnosol, Planosol
06	Groundwater Gleys	**Gleysol**, Phaeozem, Stagnosol, Umbrisol
07	Surface-water Gleys	**Stagnosol**, Phaeozem, Cambisol
08	Podzols	**Podzol,** Umbrisol, Arenosol
09	Brown podzolics	**Cambisol, Podzol,** Phaeozem, Umbrisol, Acrisol
10	Luvisols	**Luvisol**, Cambisol, Lixisol, Gleysol, Albeluvisol, Planosol, Phaeozem
11	Brown Earths	**Cambisol, Regosol** Luvisol, Phaeozem, Umbrisol, Stagnosol, Lixisol

Table 3.7 Garbic Ekranic Technosol (Densic, Toxic, Transportic) based upon definitions of formative elements for second-level units of WRB from IUSS (2015)

Classification	Meaning	Prefix/suffix intermediate (Abbreviation)	Definition of formative elements for second-level units of WRB
Technosol	Soil sealed with "technic" hard material within 5 cm of the soil surface covering 95% or more of the horizontal extent of the soil. Soil contains many artefacts	Ekranic (ek)	Rock-like sealing of concrete, tarmacadam, asphalt having technic hard rock within 5 cm of surface. Only associated with Technosols
		Garbic (ga)	Soil contains significant amount of material 20 cm or more thick within the first 100 cm. The artefacts contain >35% or more organic wastes in Technosols
		Densic (dn)	Natural or artificial compaction within 50 cm of the soil surface prohibiting root penetration
		Toxic (tx)	Has a layer with toxic concentrations of organic/inorganic substances other than ions of Al, Fe, Na, Ca and Mg, within 50 cm of the soil surface
		Transportic (tn)	A layer >=30 cm with liquid or solid material that has been moved from source by intentional human activity

and should be selected, to the extent possible, at a high level of generalisation. Similarly, within the Irish SIS, classification at Great Soil Group level considers the main soil forming processes with classification at Soil Subgroup level taking diagnostic criteria into account. Table 3.6 by Reidy et al. (2014) shows the RSG that Irish Great Soil Groups are correlated to. For example, Irish Great Soil Group 01, Ombrotrophic Peat correlates with RSG Histosol, with the Ombric suffix qualifier. A full table of the current WRB correlation for each representative soil profile at Soil Series level is also available from Reidy et al. (2014).

While some WRB prefix and suffix qualifiers may not so readily correlate and might require laboratory data not measured in the SIS, currently most Great Soil Groups readily correlate with the RSG of the WRB. The WRB is an on-going evolving process and correlation of the Irish SIS with WRB designations is important for collaboration and the presentation of work at an international level.

Fig. 3.11 Urban soils. **a** Ekranic Technosol, a pavement with constructed deposits below, formerly a tramline, road base, and embankment. **b** Regosol, formed during soil relocation as cut-and-fill for highway construction; this will eventually be given a topsoil cover and grass seed sown. **c** Garbic Technosol (Thapto-Fluvisolic), reclamation deposits of commercial garbage, with many artefacts such as bottles; beach sediments lie a further 80 cm below the base of this hand-dug pit. **d** Regosol (Relocatic), a reclamation deposit over a worked-out sand pit, showing remnants of former site soils, roughly mixed

3.9 WRB Classification for Urban Soils

Concepts for discussing urban soils have been developed by the SUITMA series of conferences (Soils of Urban, Industrial, Transport, Military and Mining Areas), and by ICOMANTH (International Committee on Anthropogenic Soils of the United States Department of Agriculture). In relation to classification, many informative names for urban soils come from the WRB for Soil Resources (IUSS Working Group WRB 2015). The WRB for Soil Resources includes many concepts that can help with describing urban soils, and how to recognise human action in soils everywhere. "Transportic", "Relocatic" and "Aric" qualifiers in soil names refer to soil moved long distances (such as in trucks), short distances (using diggers), and mixed without moving, so soil layers are disrupted. These transformations occur during construction, but also in many historical agricultural operations such as burying dead animals, bringing up limestone to spread on the land surface, installing and removing drains and earthbanks. Soils that have been mixed do not have horizons, and are called Regosols. The soil name "Technosol" was coined in 2006, and represents soils with sealing (including by buildings and roads, carparks and other "pavements") OR soils with a high proportion of artefacts (including all products of manufacture, wastes, ash, oil, and mine spoil). A narrower concept is Ekranic Technosol, with the "Ekranic" qualifier specifically referring to soils sealed by constructed rock-like material such as concrete, tarmacadam or asphalt. This qualifier is only associated with the Technosol group and goes before the name, as do qualifiers for intermediates between groups. Further qualifiers are listed in brackets after the name, giving very informative soil names. Table 3.7 provides an example of an urban soil type, using the WRB approach to naming:

The Garbic Ekranic Technosol (Densic, Toxic, Transportic) soil is primarily a Technosol. It has two characteristics typically associated with Technosols, the more-important one being that it is sealed by a “technic hard” material such as concrete or asphalt (Ekranic), and secondly that it includes a significant amount of material derived from organic wastes (Garbic). The order of Irish SIS nomenclature is consistent with the order described here for the WRB. Further characteristics identifiable under field conditions are listed, in alphabetical order. The soil is denser than will allow growth of roots (Densic); it contains substances toxic to organisms (Toxic); and it has been moved from another site (Transportic).

A few more examples show some variation among urban soils:

Arenosol (Relocatic)

Regosol (Densic, Technic)

Spolic Technosol (Thapto-Fluvisolic)

Arenosol is a sandy soil, while Relocatic identifies it as having been reconstructed without being removed from the site. A Regosol is a soil with no distinct horizons from soil-formation processes; Technic shows it as having significant artefact content (but not enough to qualify as a Technosol). Spolic Technosols represent industrial waste or mine spoil, while Thapto-Fluvisolic identifies underlying buried (Thapto-) sediment derived from flowing water (Fluvisol[ic]).

The full system, for naming all soils in the world, is published by IUSS Working Group WRB (2015). Examples of urban soils with their WRB names are given in Fig. 3.11.

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