SOIL GEOGRAPHY

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Contents

Summary

Soils are natural dynamic bodies on the surface of the Earth, capable of supporting plant growth. Their uniqueness lies in the fact that they are a mixture of mineral and organic components, with a typical morphology in layers or horizons that determine a certain profile. Although known in ancient times, it was with the scientific development of the eighteenth century that their academic study began. A soil constitutes a system of several interrelated factors such as climate, organisms, relief, and rock material, changing in time and space. A soil is defined by its physical, chemical, organic and biological properties. In the development or genesis of a soil, elementary processes of translocation and removal of material take place, creating the main types of soils. Due to the importance of soils for agriculture and forestry, the environmental processes of degradation and erosion are very relevant to society. Techniques of soil conservation and of evaluation of erosion risks have been developed, but most of all good environmental attitudes are also needed.

1. Concepts and definitions

The word soil, in a very broad sense, refers to all the unconsolidated material at the earth's surface capable of supporting plant life, the natural medium for plant growth. Soils are natural dynamic bodies on the uppermost layer of the earth, exhibiting distinct organization of their mineral and organic components, including water and air. They formed in response to atmospheric and biological forces acting on various kinds of parent material under diverse topographic conditions over a period. Soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth; it differs from parent material below in morphology, physical properties and constitution, chemical properties and composition, and biological characteristics. Like skin, the soil is constantly eroded at its surface by wind, water and man's activities, and being renewed at its base by weathering of its parent material.

Man's perception of soil differs according to the use made of it. For a soil scientist it is an organized body system of nature. The agronomist and forester look at the soil as a substrate for plant growth. An engineer sees the soil as the physical ground to support buildings, industries, bridges, roads and highways. For a landscaper it is a resource to beautify parks and gardens. From a geological viewpoint, the soil is an epidermal unit of a geologic body.

Within geography, the soil is an element of the physical environment that varies in space and time—a good to preserve from degradation and erosion. There is a strong relationship between soils and the other branches of physical geography. In geomorphology, for instance, there are texts linking both subjects, like the ones from Birkeland, from Richards *et al* and from Conacher and Dalrymple. Even more evident is the relationship between soils and vegetation, in such a way that sometimes the study of soils is incorporated in the biogeography textbooks, like the one from Duchaufour. Also, in hydrology there are interrelationships that need to be understood when studying infiltration and water movement within the soil. In the case of climatology, the relationship is strong but inverse, i.e. there are the climatic characteristics that determine to a great extend the soil type and development.

2. Historical background

Before 1600, the references to soils are very elementary and often related to their agricultural productivity. It was with the birth of geology at the end of the eighteenth century that the scientific study of soils began. Fieldwork demonstrated the difference between sediments and soils, and their development by weathering of the rock. So for many years soil was considered as part of geology, simply the loose fraction of the Earth's crust. Further more, the chemistry applied to agriculture showed that the vegetation takes nutrients from the minerals in the soil, and that chemical reactions and cation exchanges took place within the soil.

The study of soil as a science is a recent advancement, related to the fields of geology, geography, chemistry and biology, which began to emerge following the Renaissance. In the eighteenth century, geographers were classifying and mapping soils in Great

Britain. In 1862, in Germany, Friedrich Fallou coined the term pedology (from the Greek *pedon*) for the scientific study of soils.

It was in Russia where the scientific study of soils began, initially with Lomonosov, who wrote and taught about soils considered as an evolving body. In the 1880s, the physical geographer Vasili Dokuchaev recognized soil as a natural unit worthy of study in its own right. He was the first to consider a soil as complex mixture of mineral matter, organic matter and living organisms, a product of the environment, constantly changing and evolving, sometimes very slowly, like in dry desert areas, or more quickly in wet tropical regions. In 1876, at an interdisciplinary commission organized in Russia to study the chernoziom soil, Dokuchaev developed the fundamentals of soil investigation. Numerous other scientists (e.g. Konstantin Glinka) made their contributions to the development of soil science over the years. In USA, Eugene Hilgard wrote about alkaline soils and the relations between soils and climate, landforms and vegetation. Curtis Marbut, a geomorphologist, viewed the multiple and interdependent processes in the development of soils.

The importance of the progression of the scientific study of soils was clearly established in the first international meetings dedicated to it. In the conferences of Budapest (1909), Stockholm (1910) and Prague (1922) the term Agrogeology was used, which shows the importance that geologists had in the development of this science and the dominant interest for cultivated soils. However, in the conference of 1924 in Rome (1924) the wider expression "Soil Science" was adopted, a term that was also applied to the first International Society issued from that meeting. Another term also used in the study of soils is edaphology, from the Greek *edafos*.

In 1941, Hans Jenny, considering the soil as a system, presented the conceptual equation:

$$S = f\,(cl, o, r, p, t, n.) \qquad (1)$$

where soil (S) is a function of climate (cl), organisms (o), relief or topography (r), parent material (p), time (t), and unspecified factors (n), one of which includes human activities. His work synthesized the concepts of the time and became a paradigm of soil science that is still followed today. In 1961, he derived another equation, taking into consideration the soil as an open system where energy and matter come in and out. The equation is:

$$\mathrm{e, s, v, a = f\,(I, F, t)} \qquad (2)$$

The parameters used are: the properties of the ecosystem (e), the properties of the soil (s), the properties of vegetation (v), and the properties of animals (a), which are function of the initial state of the system in relation to the parent rock, topography, slope and exposure (I), the external flux potentials constituted by organisms and climate (F), and the age of the system (t). At a certain time interval the changes in the properties of the system are equivalent to the income less the losses, and then:

$$\mathrm{e, s, v, a = f\,(cl, o, r, m, t, n)} \qquad (3)$$

Neither the topographic factors, nor the parent rock is dependant on time, while climate and organism may or may not be a function of this parameter.

To study the development of a soil it is necessary to refer to the different individual actors, i.e. to consider the situations in which only one factor varies while the others remain constant. Because this is practically impossible, the only possible approach is to expect that variations will be so small that they can be ignored. It is then possible to establish sequences as functions of a dominant factor:

S = f (cl) o, r, m, t, n (function of climate)
S = f (o) cl, r, m, t, n (function of organisms)
S = f (r) cl, o, m, t, n (function of relief)
S = f (m) cl, o, r, t, n (function of lithology)
S = f (t) cl, o, r, m, n (function of time)

3. The soil profile

Whereas soil is formed from the rock below, at the same time it is eroded away from the top. A cover of plant life slows down erosion, allowing the soil layer to build up. In this process a characteristic morphological feature develops, the soil profile, composed of several differentiated layers or horizons. Naming of horizons differs depending on the soil classification used. Here the U.S. Soil Taxonomy System will be used, although only their master horizons.

O horizons. On the surface of the soil often a layer is found, rich in leaf litter and other organic material more or less decomposed. Some are saturated with water or were once saturated.

The A-horizon is the mineral layer that has formed. It exhibits obliteration of all or much of the original rock structure and show one or both of the following: (1) an accumulation of humified organic matter closely mixed with the mineral fraction, or (2) properties resulting from cultivation, pasturing, or similar kinds of disturbance. It is also where most plant roots and soil organisms are found.

The conjunct of the O and A horizons constitute the solum, which is the part of a soil body in which the parent material has been modified and plant roots are contained. It is also where the effects of climate and biological activity are most pronounced.

The E horizon is a mineral layer where the main feature is the loss of silicate clay, iron, aluminium, or some combination these, leaving a concentration of sand and silt particles. This horizon exhibits obliteration of all or much of the original rock structure.

By comparison, the B-horizon is the zone where new material from below and nutrients from above accumulate. Sometimes an impermeable layer or pan is formed above it, denying plants to access this rejuvenating source of new nutrients. It has formed below an A, E or O horizon and it shows much of the following:

- illuvial concentration of silicate clay, iron, aluminium, humus, carbonates, gypsum, or silica, alone or in combination,
- evidence of the removal or addition of carbonates,
- residual concentration of oxides,
- coatings of sesquioxides that make the horizon conspicuously lower in colour value, higher in chroma, or redder in hue, without apparent illuviation of iron,
- alteration that forms silicate clay or liberates oxides, or both, and that forms a granular, blocky, or prismatic structure if volume changes accompany changes in moisture content,
- brittleness or
- strong gleying

Just above the base rock, is the C-horizon, containing the recently weathered and still weathering soil. It is little affected by pedogenic processes and lacks the soil properties found in the other horizons. The material may be either like or unlike the material from which the solum has presumably formed. It may have been modified, even if there is no evidence of pedogenesis.

R layers. Strongly cemented to indurated bedrock. This is sufficiently coherent when moist to make hand digging with a spade impractical, although it may be chipped or scraped. The cracks may be coated or filled with clay or other material.

W layers are layers filled with water within or beneath the soil.

Horizon	**Description of detailed soil horizons**
O	Consists mainly of organic matter from the vegetation, which accumulates under conditions of free aeration.
A	Eluvial (outwash) horizon consisting mainly of mineral matter mixed with some humified (decomposed) organic matter.
E	Strongly eluviated horizons having much less organic matter and/or iron and/or clay than the horizons underneath. Usually pale coloured and high in quartz.
B	Illuvial (inwashed) horizon characterised by concentrations in clay, iron or organic matter.
C	Weathered parent material lacking the properties of the solum and resembling more the fresh parent material.
R	Regolith, the unconsolidated bedrock or parent material.

Table 1. Soil master horizons.

Soil and top soil are produced naturally at a rate of 1mm in 200 to 400 years, averaging at about 1 ton/ha/y. A full soil profile develops in 2000 to 10 000 years, a period that is long for humans but short for the planet. World-wide, agricultural soil is lost at a rate 10 to 40 times faster than its natural replacement.

The USA lost 80 mm since farming began, 200 years ago. This amounts to some 18 t/ha/y. China appears to lose 40 t/ha/y. World-wide loss of agricultural land is 6 million ha per year, from a world-wide total of 1200 million ha (0.5%/y). These are compelling reasons for improving the way humans manage their soils.

Figure 1. Soil profile (podzol FAO, spodosol STS).

4. Soil properties

4.1. Soil physics

Soil physical properties are those related to their inorganic portion, and they are extremely important from both internal characteristics and productivity standpoints. Minerals come from a variety of sources, but the key process is physical weathering of rocks by the actions of wind, rain, ice, sunlight, and biological pressures, which break them down into smaller particles. A portion of this material is soluble in water, and thus easily taken up by plants, and a much more bulky portion is insoluble.

The way in which a soil is put together, or its architecture, is related to its physical properties, such as texture, aggregation and porosity. The movement of air, water and solutes through the soil is dependent on the spaces and their configuration among the soil particles. This will also affect soil temperatures and the soil's ability to store water.

Physical properties such as colour, texture and structure are used in soil classification, particularly in horizon definitions. All these properties affect how easily the soil will support living organisms or how well it will support a building.

Soil texture is a reflection of the distribution of particle size fractions or the relative amounts of sand silt and clay. Fine textured soils contain more clay size minerals and have relatively high porosity but the pores are small and often discontinuous. In contrast, coarse textured soils contain sand sized minerals and have more porosity but bigger pores that are connected. Soils are made up of a mixture of particles ranging from clay size of less than 2µm to gravels and stones. Smaller particles are often cemented together by organic matter, iron oxides, plant roots, etc. and form the fundamental structure of soils as aggregates. If we remove the cementing material and disperse the particles in water we can *separate* the individual particles by sedimentation. The coarse particles settle first, the fine particles last.

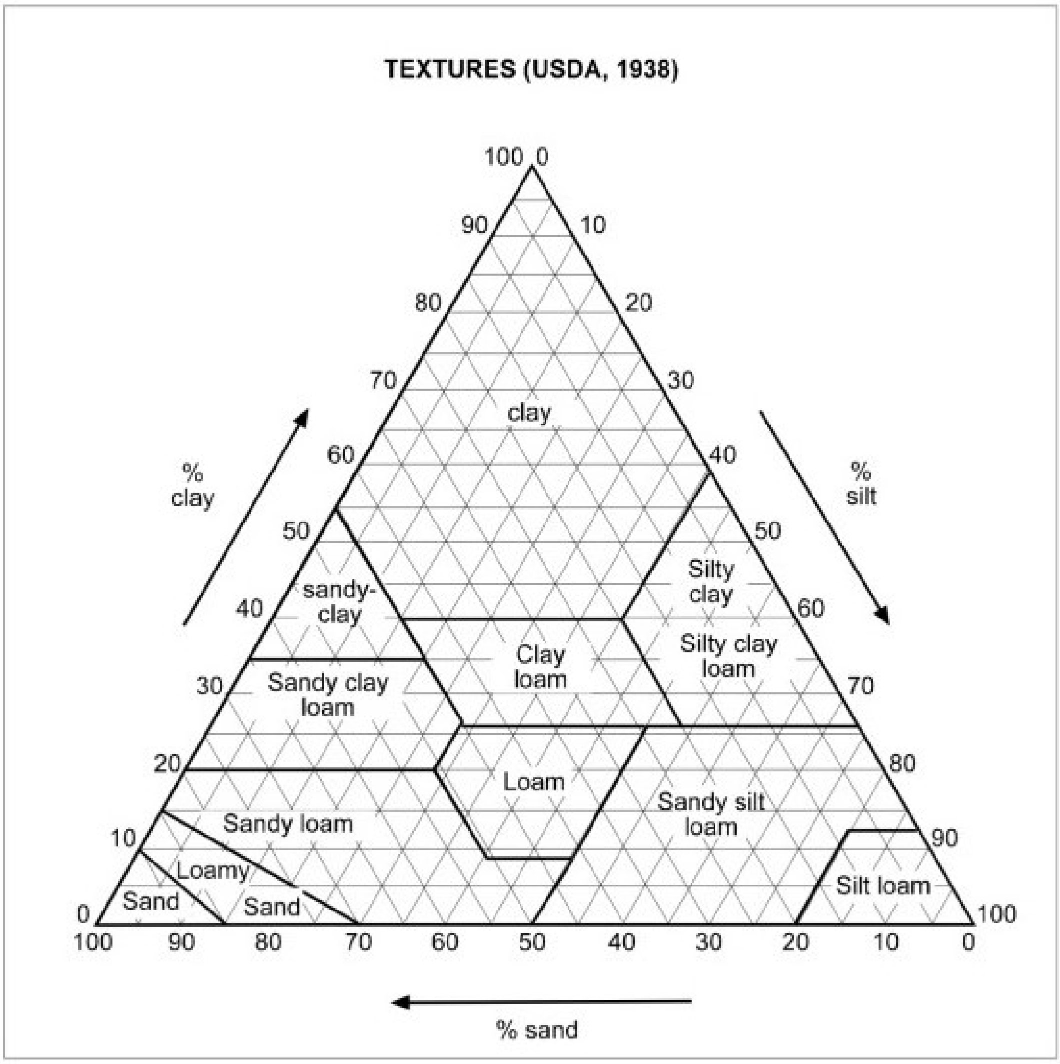

Figure 2. Particle-size classes

The term structure refers to grouping of the primary soil particles into secondary clumps or aggregates, often called peds. In relation to its shape a structure can be classified as granular, blocky, laminar, or prismatic. Structure is important to components that flow such as water, air, heat, and nutrients. In a prismatic structure, for instance, the vertical cracks allow for rapid downward water movement and root growth. Chemical conditions, such as pH and salinity, can severely affect structure. Organic matter content is also an important component for the development of soil structure.

Bulk density is the mass of one cm^3 of the soil, which includes both solid particles plus the voids among particles or the pore space. Porosity is derived mathematically from bulk density and the density of the soil solid particles or particle density. The size of soil particles and how they are clumped together or aggregated largely determines the bulk density and porosity.

As for colour, accumulations of oxidized iron compounds give red chroma, while loss of organic matter and iron compounds gives light coloured grey horizons. Red and brown mottled horizons are indicative of reduced conditions or water logged soils.
Soil water holding characteristics are important for dry land farming, selection of the correct irrigation system, irrigation scheduling, crop selection, and ground water quality.

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Bibliography

Birkeland P.W. (1984). *Soils and Geomorphology*, Oxford University Press, N.Y. [A usefull textbook to serve the needs of geomorphologists, sedimentary petrologists and archelogists working in Quateranry research, with emphasis on their natural settings]

Buol S.W., Hole F.D. and McCraken, R.J. (1980). *Soil genesis and classification*. Iowa State University Press. Ames.[A classical textbook on soils]

Duchaufour P. (1970). *Précis de Pédologie*, Masson & Cie, Paris. [A French textbook dealing with soil properties, genesis and evolution and applied pedology. Interesting to note the classical soil classification]

Fanning D.S and Fanning M.C.B. (1989). *Soil. Morphology, Genesis and Classification*, John Wiley, New York. [A textbook for advanced undergraduate courses. Most of the text is directed towards genesis and the US soil classification]

Paton T.R., Humphreys G.S. and Mitchell P.B. (1995). *Soils: A New Global View.* Yale Univ.Press .New Haven. [This book challenges the prevalent view of the characteristics and origins of soils, exposing the inadequacies of climate determinism and the reliance on zonalism.]

Trudgill S.T. (1988). *Soil and Vegetation Systems.* [This presents the study of inputs, outputs, reactions, and stability in soil and vegetation systems.]

USDA Soil Conservation Service (1988). Soil Taxonomy. Robert E. Krieger Publishing Co. Malabar, Florida. [Basic tool for soil classification]

Yaalon D.H. and Berkowicz S. (eds.) (1997). *History of Soil Science. International Perspectives*. Catena, Reiskirchen, Germany. [A collection of 22 papers presenting a wide international perspective on the History of Soil Science.]

Biographical Sketches

Maria Sala is Titular Professor of Physcial Geography at the Department of Geography and Regional Science, University of Barcelona, and has a BA (Honours) degree in Geography (Physical Landscapes) and a PhD (Honours) degree in Geography (Fluvial Geomorphology) from the University of Barcelona.

Maria Sala leads the GRAM, Mediterranean Environment Research Group, which is recognized and funded by the University of Barcelona and the Catalan Autonomous Government. Her current research interests lie in the fields of fluvial geomorphology, soil and slope erosion, catchment hydrology and water quality. Work in these fields has mainly been undertaken in the Catalan Coastal Ranges although through cooperative work she has done research in UK, German Alps, Tunisia, Portugal, Argentina and Mexico. Fundamental research is applied to environmental problems, mainly increased runoff and flooding as a result of expanding urban land use and forest fires. Recent and current research has attracted substantial funding from a number of sources including CICYT (Spanish Ministry of Education), CIRIT (Catalan Council for Research), and the EU.

Current investigations include: Hydrology and sediment dynamics in Mediterranean mountain catchments, Effects of prescribed burning in soil parameters and in increased runoff and erosion, Morphological changes and sediment transport in the bed of a Mediterranean river, Fluvial transport of suspended material: sources, routing, storage and yield.

She has been visiting scientist at the Centre de Géographie Appliquée, Université Louis Pasteur, Strasbourg, under the guidance of Professor Jean Tricart (Climatic geomorphology, 1975) and at the Department of Geological Sciences, Seattle, under the guidance of Professor Thomas Dunne (Fluvial and slope processes, 1984).

Regular courses taught include: Physical Geography, Geomorphology, Erosional Processes in the Slopes, Hydrology of Surface Waters, Theory and Methods in Physical Geography, Fluvial Geomorphology, Hydrography and Soil Geography. Invited courses include: Geomorphological Processes, at the Departamento Geografía, Universidad Autónoma, México, (1983), and Fluvial and Slope Processes, at the Departamento de Geología, Universidad de Salta, Argentina (1991). At a European level she is the Spanish coordinator of an ERASMUS Inter-University Cooperation with the Universities of Strasbourg, Amsterdam, Barcelona, Berlín, St. Andrews, Upsala and Cáceres.

Maria Sala has contributed to several research groups, like the European Society for Soil Conservation (ESSC), where she has serveds as Vice-President (1988 -1992) and Council Member (1988-1996), and the International Geographical Union, where she has been the Chair of the Study Group on Erosion and Desertification in Regions of Mediterranean Climate (1992-1996) and of the Commission on Land Degradation and Desertification (1996-2000). She is member of several International Journals Editorial Boards, such as Earth Surface Processes and Landforms, Zeitschrift für Geomorphologie, and Geomorphology of Brazil Journal. And she belongs to the Technical Advisory Committee of the Centre for Environment and Development for the Arab Region and Europe, CEDARE (since 1990).