THE SIXTH FACTOR OF SOIL FORMATION

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"Human beings are all interlocked with plants, animals, soils and waters, in one humming community of cooperation and competition: one biota. They are related and bound into a seemless fabric" (Aldo Leopold, 1949).

Introduction

Since the beginning of mankind soil has been the basis for the sustenance of life. In early times modification of the soil by man must have been mostly unintentional, induced largely by vegetation changes, many of them caused by fire. With the advent of agriculture and the first domestication of plants and animals, there has been increased intensity of the use of soil resources. Human interventions were either direct – through plowing, liming, manuring, fertilizing – or indirect through changing the natural soil forming factors – changing the vegetation by deforestation, changing the relief by leveling and terracing, changing the moisture regime through irrigation and drainage, changing the parent material through transport, dumping or the exploitation of peat and rocks, through erosion and sedimentation. Even when populations were small and technologies simple, these effects might cumulatively, through time, be considerable (Proudfoot, 1972). This impact has become more important and widespread through steadily increasing population pressure and the development of human cultures. Early lithic tools evolved into iron plowshares, coulters and spades which in turn made place for heavy tillage machinery. Early manuring evolved into the use of manufactured fertilizers, of which up to 140 million tons of nutrients are now applied yearly. Irrigation, developed locally millennia ago, expanded to the current 260 million hectares. Concurrently terracing and land leveling were practiced over vast areas. Large areas of wetland have been drained through polders and reclamation. Presently cultivated land encompasses about 1.5 billion hectares worldwide. Expanding urbanization and industrialization, infringing on areas of agricultural land, have further influenced soil characteristics through sealing, excavations, pollution and waste disposal. Population estimated at 250 million people at the start of our era has now reached 6 billion and it is still increasing. Hence, human influence on soil formation is much more pronounced and extensive than originally perceived.

The human factor of soil formation

Of the classical factors of soil formation, climate, relief, parent material, time and organisms, it is the latter factor which discretely includes human impact. However, soils modified by human activities were often labeled as 'disturbed', 'artefacts', 'manipulated' or 'artificial' and were considered to be 'deviations' rather than a part of the soil continuum.

It is not appropriate that human impact be integrated in the soil forming factor 'organisms'. Humans differ from other species in the animal kingdom by their capacity for abstract reasoning and the development of culture. Human impact is goal directed and differences between societies produce different effects on the environment (Amundson and Jenny, 1991). Successive human communities have left a conscious imprint on the soil scape. The temporal scale of human modification may be much shorter than the time frame in which most natural pedogenic processes operate but, while humans are members of the biotic team, their technologically-magnified power to impact nature sets them apart. The anthropogenic factor can act both dependently and independently of the other soil forming factors (Pouyat and Effland, 1999). They are interdependent in cases where human influences occur on time scales similar to 'natural' soil formation such as terracing, irrigation, drainage, change in vegetation. Metapedogenesis (Yaalon and Yaron, 1996) begins after the 'natural soil' has been formed, however, human influence has also had an impact on early soil behaviour. Hence, man is an integral part of the ecosystem and of the biosphere (Di Castri, 1981). So-called 'agents of disturbance', whether fire, farming, grazing, predators or man, which have been viewed as acting from outside to subvert 'normal successional stages', are actually functional components of the ecosystem (Leopold, 1949). The switch from 'man the outsider' to 'man the insider' marks a change in concept and elevates him to a fully fledged factor of soil formation, a sixth one in addition to the five traditional ones. The escalation and intensity of human occupation and activities over the last two hundred years have been such that they may even justify the recognition of a new geological epoch, the Anthropocene (Crutzen, 2002), in which humans are a significant and sometimes dominating force, contributing to global soil change (Arnold et al., 1990).

The ignorance or the overlooking of human influence on soil formation has had a detrimental effect on the representativeness of soil classification of the realities of the soil universe.

Although soil management practices and other human interventions have been forcefully acknowledged as having an impact on soil formation (Edelman, 1954; Bidwell and Hole, 1965; Yaalon and Yaron, 1966), early soil classifications have not systematically catered for soils that have been modified by human activities. It is the present recognition of a sixth human factor of soil formation that has triggered considerable attention to the characterization and classification of 'man-made' or 'anthropogenic soils'.

Anthropogenic soils

The term 'anthropogenic soils' is used here in a generic way. Because of the widely different kinds of human interventions and the broad range of soil conditions that result from them, it would not be appropriate that they be considered in bulk in a classification system. Moreover, terms reflecting a soil forming process are no longer used in modern soil nomenclature. Lithogenic limestone soils, climogenic tropical soils, topogenic mountain soils or temporal young soils, connotative of a dominant soil forming factor, are no longer distinguished as such in present day soil classification systems. Neither have former phytogenic forest soils or prairie soils been retained.

The diversity of 'anthropogenic soils' has given rise to a proliferation of different units such as Agrozems, Anthrepts, Anthrosols, Anthrozems, Hortisols, Kultizems, Quasizems, Rigosols, Treposols, Urbanozems and many others. This rather unwieldy name giving needs to be remedied by a further precision of concepts. In order to avoid a splintering of classes, it may be useful to identify the main types of man-made soils on the basis of which a more systematic characterization and subdivision could be envisaged (Dudal et al., 2002).

There appear to be six major types of 'anthropogenic soils':

a. Human induced changes of soil class
b. Human-made diagnostic horizons
c. Human induced new parent materials
d. Human induced deep soil disturbance
e. Human induced change of landform
f. Human induced topsoil changes.

a) Human induced changes of soil class

Soils of which the diagnostic horizons have been modified by land use practices.

Examples are[†]:

- Solonchaks (Salids) developed from Cambisols (Cambids) in arid environments as a result of irrigation
- Plinthosols (Petroferric Udepts) resulting from the emergence and hardening of plinthite near the surface, caused by erosion of Plinthic Acrisols (Plinthudults)
- Regosols (Orthents) arising from the total truncation of a Luvisol (Hapludalf) formed from deep loess
- Anthraquic Nitisols (anthraquic Kandiudults) which develop from Haplic Nitisols (typic Kandiudults) subjected to surface waterlogging associated with long lasting rice irrigation
- Cambisols (Ochrepts) resulting from the artificial drainage of Gleysols (Aquepts)
- Orthithionic Fluvisols (Sulfaquepts) derived from Protothionic Fluvisols (Sulfaquents) through drainage
- Luvisols (Hapludalfs) developed from Albeluvisols (Fraglossudalfs) by many centuries of bioturbation associated with liming and manuring (Langohr and Pajares, 1983).

Although such soils are 'anthropogenic', and one should be fully aware that they are, their morphology is not basically different from that of 'natural' soils. Hence new classes or new names are not required. Their widespread occurrence reflects the importance of the human factor of soil formation on the composition of the present soil cover.

b) Human-made diagnostic horizons

The formation of 'new' diagnostic horizons or features resulting from long term applications of organic matter or of wetland cultivation.

These soils have been grouped under the term 'Anthrosols' in the World Reference Base for Soil Resources (FAO/ISRIC/ISSS, 1998). In Soil Taxonomy (Soil Survey Staff, 1999) human induced enrichment of organic matter has been captured in the plaggen and anthropic epipedons. In the Soil Classification for England and Wales (Avery, 1980) these soils are grouped as 'Man-made humus soils', one of the ten major soil groups. In the German soil classification (DBG, 1985) they are distinguished as an order of 'Anthropogenic soils'. The new Russian soil classification (Shishov et al., 2001) distinguishes Agrozems at order level for soils which display human induced 'new' horizons. In the WRB the organic matter enriched soils are split into plaggic, terric and hortic Anthrosols according to the practices involved. The wetland accumulations of silt are named irragric Anthrosols, while the

[†] The nomenclature used is one of the World Reference Base for Soil Resources (WRB) (FAO/ISRIC/ISSS, 1998) with , in brackets, the equivalent in the USDA Soil Taxonomy (Soil Survey Staff, 1999).

anthraquic horizons of rice-irrigated surface waterlogged soils are distinguished as hydragric Anthrosols.

c) Human induced new parent materials

Unconsolidated mineral or organic soil materials resulting largely from landfills, mine spoil, urban rubble, garbage dumps, dredgings, produced by human activities generate fresh 'anthropogeomorphic' parent materials upon which soil forming factors can start acting anew (Kosse, 2000).

It is this type of 'anthropogenic soils' that has received most attention and for which a number of names have been suggested: Spolents (Sencindiver et al., 1978), Potisols (Fanning et al., 1978), Depo-subgroups and Methanosols (Blume, 1989), the latter for organic wastes which break down anaerobically and cause the build-up of methane in landfills. In Russia (Shishov et al., 2001) the 'Technogenic Superficial Formations' are considered separately from the actual soil classification, the composition and origin of landfill materials being criteria for a further subdivision. Soils of sealed surfaces, under roads or buildings, are also recorded in order to provide data on the kinds and areas of soils which are lost to urban and industrial development (Blume, 1989). In the WRB these soils were not retained as Anthrosols on account of not having been subject for a sufficiently long period of time to pedogenetic processes. They are assigned to the Regosols (Entisols) qualified at subgroup level in accordance with the origin of the anthropogeomorphic material (spolic, garbic, urbic).

d) Human induced deep soil disturbance

This type of anthropogenic soils refers to deep plowing, ripping, battlefields, trenches, excavations, pipelines, construction sites, cemeteries, broken hardened layers or pans. These soils show no diagnostic horizons or only fragments which are not arranged in any discernible manner. Soil Taxonomy (Soil Survey Staff, 1999) recognizes Arents for these types of materials. In Germany these soils are classified as Treposols and Rigosols (DBG, 1985). The WRB accommodates them as Aric subgroups.

e) Human induced change of landform

Terracing is an agricultural technique with a long history that has transformed landscapes and soils in many parts of the Americas, Asia, Africa and Europe (Sandor, 1998). Early ages for terracing are approximately 3000-4000 years B.P. in the Near East, eastern Asia and the

Americas with possibly older ages in some regions of Eurasia (Sandor and Eash, 1995). Terracing involves segmentation of slopes which transform the landscape into stepped agro-ecosystems. Slopes are reduced in angle and length, influencing hydrology, erosion and sedimentation in order to ensure soil and water conservation. Familiar forms of terracing include irrigation terraces of Southeast Asia, bench terraces in mountainous terrain, runoff terraces in arid regions, and lynchet and rideaux fields in northwestern Europe. On long, slightly sloping terraces, the original profile may still be present. However, on short range terraces the soil may be entirely reconstituted through a cut-and-fill process by which the lower part of the terrace surface horizons are buried while part of the pedon is truncated in the upper part. Furthermore soils are influenced by anthropogenic colluviation. On irrigated terraces anthraquic horizons are likely to develop. Terraces occupy very large areas in different parts of the world and it is unclear how they have been dealt with in soil surveys and classification. The human influenced modification and their extent are such that they need to be identified and delimited. Other changes in landform that need to be considered are mined areas, raised fields and levees.

f) Human induced topsoil changes

The most pervasive and extensive forms of human induced soil characteristics are the changes which affect the topsoil as a result of tillage, deforestation, liming, marling, fertilization, manuring, irrigation, drainage, erosion, fire, contamination by heavy metals or nuclides, pollution by acid aerial deposits or biocides. Topsoil is of prime importance for soil management, soil fertility and crop production. It is the layer where seeds germinate, where the bulk of plant roots develop, where biological activity is most intense, where a major part of applied plant nutrients are stored, where improved or degrading farming practices have their major impact. Yet, topsoil characteristics have not received a prominent place in current soil classification systems, in favour of subsurface horizons considered to be more stable over time. It was generally felt that 'transient properties' produced by plowing and normal agricultural practices should have the least possible effect on the placement of soil in a classification system. As a result soil survey interpretation is often flawed on account of differences in the topsoil of natural and cultivated soils belonging to the same class. This shortcoming may be the main cause of many frustrated attempts to establish relationships between soil taxa and response to fertilizer applications.

There is a major difference in productive capacity between an acid 'natural' Podzol (Spodosol) or Acrisol (Ultisol) and one which has been improved through long-term manuring and fertilization. Yet the modification of organic matter content and the improved base status of the topsoil do not allow for separation of these soils in current soil classification systems. The same applies to considerable variations resulting for example from liming, erosion of topsoil upon deforestation, destruction of organic matter through forest fires, increased mobility of heavy metals as a result of surface acidification, heavy metal contamination through industrial wastes, compaction by heavy machinery, fertilizer and trace element applications, or topsoil 'conditioning' with polymers. On the one hand differences between soil classes are reduced by the equalizing effect of 'good land husbandry' while on the other hand, differences are created within soil classes, as a result of different management practices and exposures to external emissions.

Anthrosols revisited

Because of the importance and extent of anthropogenic soils, it is imperative that they be localized and characterized for purposes of land evaluation, land use planning and environmental protection. A number of proposals have been made to define soil classes and to coin names to accommodate them, however, no consensus has been reached as to which basic principles should apply. A first principle which would be worth adhering to is that soils are defined on the basis of their morpho-analytical characteristics – of what they are – and not on account of their genesis – of how they have been formed. A second principle could be that human influence is recognized as a fully fledged soil forming factor so that anthropogenic soils are no longer considered as 'deviations' but should be accommodated within existing classification systems. A number of national schemes have introduced a class of Anthrosols, Anthroposols, Anthropogenic or Man-made soils at the highest level of generalization (Avery, 1980; DBG, 1985; FAO, 1988; Baize et al., 1992; Hewitt, 1992; Isbell, 1996; FAO/ISRIC/ISSS, 1998; Gong Zitong, 1999). With a view to incorporating anthropogenic processes in Soil Taxonomy it is being considered to introduce an order of Anthrosols to be placed at the beginning of the key (Bryant and Galbraith, 2003). The advantage of distinguishing anthropogenic soils at the highest level is that it enhances the visibility and awareness, to both soil scientists and landusers, of human influence on the resource base. The disadvantage is that an order of Anthrosols would be extremely heterogeneous, stretching the variability within one category beyond a classification logic. It is suggested therefore that the terms 'Anthropogenic soils', 'Anthrosols', 'Anthroposols' and the like be used only in a generic way but that they not be retained to name soil classification

units, at any level. A selective classification will be required in order to distinguish the six main types of anthropogenic soils, described above.
The soils which have shifted to another class as a result of human influence (type a) could be accommodated within existing reference groups, with an anthric qualifier when justified by observable characteristics (Nachtergaele et al., 2002).
The man-made humus soils (type b) which have undergone long and continuous human influence, need to be recognized as a separate group, under a name to be selected among existing proposals such as hortisol, agrisol, agrozem and others, qualified in accordance with the nature of the organic accumulation. Soils (type b) showing an anthraquic horizon could be an anthraquic subgroup of the soil from which they are derived. When the anthraquic concept was launched (Dudal and Moormann, 1964) it was felt that the diagnostic features underlying the paddy layer (Dudal, 1956; Jung and Eswaran, 1990) were sufficiently important to give them precedence. Soils with irrigation sediments (type b), if sufficiently thick, may well qualify as Fluvisols (Fluvents) with an irragric qualifier.
Soils from human induced new parent materials (type c) have received considerable attention on account of steadily growing urbanization and industrialization entailing transport of materials, disposal of wastes, sealing of surfaces and various forms of technogenic operations. Landfills and dumps are a form of 'entisolization' (Dazzi, 1995) resulting from a one-off human intervention upon which soil formation starts anew. As a result WRB has grouped them with the Regosols (Entisols) qualified in accordance with the nature of the new parent material (garbic, spolic, urbic). Others consider that because of the lack of soil genetic processes the classification must be based on the features of the substrate. The anthropogeomorphic deposition is equated with a lithological and geological origin of parent material (Burghardt, 2000). A dual track or multicomponent classification is advocated separating 'natural soils' from 'technogenic superficial formations' (Tonkonogov, 2001). It is also envisaged to create a group of Technosols which would be characterized by the type of new material rather than by profile morphology (Rossiter and Burghardt, 2003). Detailed specifications and nomenclature are being proposed for the classification of technogenic materials (Shishov et al., 2001; Galbraith, 2004). If human influence is recognized to be a soil forming factor it should be attempted to incorporate technogenic soils in a unified soil classification system. The question arises however, at which level these materials should be recognized and how they would be dealt with in soil surveys. The high spatial variability, horizontally and vertically, of technogenic soils implies that they may be distinguished only at a detailed scale, often separated by straightline boundaries (Southard, 1999).

Soils which have undergone deep disturbance (type d) but show fragments of diagnostic horizons may be grouped with the original soil, qualified in accordance with the intensity and nature of the disturbance.

Soils occurring in changed landform (type e) which still show diagnostic horizons, could be distinguished by a 'scalic' qualifier (L. scala, It. scalinata, Fr. escalier, stairs, steps). In case soils are thouroughly modified they will need to be classified on the basis of newly acquired properties. The delineation of changed landforms is important not just because of modified soil properties but because of the modified hydrology of the anthropogenic landscape (Boixadera and Poch, 2000). Soil research has focussed on the pedon. Relational characteristics at the landscape scale may also need to be taken into account.

Soils which show human induced topsoil changes (type f) require special attention in order to overcome the gap between the interpretative value of soil classes and actual production potential. It has been proposed to introduce a comprehensive characterization of topsoils (Purnell et al., 1994; Baize and Rossignol, 2004) for the practical purpose of assessing and monitoring fertility status and guiding management practices. Topsoil characterization should, at an appropriate level, become an adjunct to current soil classification and provide a link with soil management. It is necessary to identify main topsoil properties related to organic matter status, biological activity, physical, chemical and moisture conditions. Topsoil should be characterized over and above the diagnostic horizons and features required for defining a soil class. This approach could help overcome criticisms from other disciplines and from land users about shortcomings in the application value of taxonomic systems.

Conclusion

Human influence on soil formation is much more profound and extensive than originally perceived. It is imperative that the anthropogenic processes be explicitely recognized as a fully fledged soil forming factor. Its impact occurs across all 'natural soils' not as a 'deviation' but as a component part of the 'genetic soil type'. The effects and geographic distribution of the anthropogenic factor are very diverse as a result of considerable differences of human interventions in space and time. In order to avoid a proliferation of classes it is desirable that 'anthropogenic soils' be integrated in a unified soil classification system. The characterization and classification of 'anthropogenic soils' is being addressed in numerous fora (Burghardt and Dornauf, 2000; FAO/ISRIC/ISSS, 1998; Galbraith, 2004; Kimble et al., 1999; Russian Academy of Agriculture, 1997; Sobocka, 2001). A number of options will have to be considered in order to reach a balance between taxonomy and applicability. The selection of class differentiae should take into account their relevance for land use. Some traditional concepts and assumptions may need to be re-examined. Should all diagnostic criteria come from within the pedon or can relational geomorphic or historic features also be taken into account? Anthropogenic processes may not cause drastic changes in soil morphology, but modify some chemical, biological and physical properties which are significant for soil management. Changes in topsoil characteristics will require special attention even though they may not have direct taxonomic implications. Too often human influence on soil formation is equated with threats of erosion, degradation or pollution. It should be realized that human interventions have also led to the conservation, reclamation and enhanced fertility of soils. Soil science will become more credible if it clearly recognizes that most soils that we use have been, and are being changed by human activities for better or for worse. This awareness and knowledge will allow for predicting the effect of new technologies, and for enhancing sustainable soil management.

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