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The genesis, classification, and mapping of soils in urban areas

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This paper discusses the concept of soil in both urban and rural environments, and along the urban-rural land use gradient, to illustrate the obvious need to increase our understanding of urban soils. Spatial variability of the urban landscape is illustrated with ''Soil series – Urban land complexes'' from Baltimore County, Maryland. The *World Reference Base for Soil Resources* (ISSS-ISRIC-FAO, 1994) proposed Anthrosol and Regosol major soil groups are discussed to show modern approaches to soil classification and to illustrate how the classification of urban soils is essentially undeveloped. Models of soil genesis help identify the processes and functions of the soil system. A conceptual model using Jenny's (1941) state factor approach for human impact on soil formation details the ''anthroposequence.'' The benchmark anthroposequence model may be applied to studying soil systems along urban-rural land use gradients. The process of ''anthropedogenesis'' is supported to quantify the role of human activity in changing the ''natural'' direction of soil formation. Future directions of soil research in the urban landscape should involve large scale soil mapping (e.g. 1:6000), benchmark anthroposequences, improved soil classification, and refined characterization of the role of human activities in soil formation.

Keywords: anthropedogenesis; urban soil; soil genesis models; soil classification

Introduction

Soils in urban landscapes form the foundation for many ecological processes such as biogeochemical cycling, distribution of plant communities and, ultimately, the location of human activities. Soils associated with urban land uses serve as both sources and sinks for numerous feedback mechanisms, and the soil system acts as a component for various ecological functions. Soils function in the urban landscape by supplying plant nutrients, serving as a plant growth medium and substrate for soil fauna and flora, and contributing to the hydrologic cycle through absorption, storage, and supply of water (Bullock and Gregory, 1991). Soils also intercept contaminants such as pesticides and other toxic substances (e.g. heavy metals) generated through human activities (Bullock and Gregory, 1991; Pouyat *et al.,* 1995). Models of soil formation or genesis must account for these human-induced processes and responses of the soil in a systematic manner.

Human activities in urban environments cause impacts on the soil that vary both spatially and temporally. Evidence of this spatial variation is shown by a continuum of ''human-altered'' soil bodies intermixed with discrete islands of unaltered ''natural'' soil bodies in urban settings such as the New York City metropolitan area and the Baltimore, Maryland-Washington, DC corridor. Temporal variability can be observed in the contrast of current activities such as land development, road construction, or mining with historical impacts to soils found in Europe, China, and elsewhere. Soil classification systems

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organize soil variability into useful groupings that can be identified by field investigation and documented in soil survey activities to promote effective resource management and technology transfer. Traditionally focused on rural agronomic land use, recent soil surveys have initiated activities such as large-scale mapping to address soil variability in urban regions. For example, the Fairfax County, Virginia Soil Scientist Office conducted large-scale soil mapping (1:6000) and published the County of Fairfax Soil Identification Maps for use during subdivision planning and review.

This paper discusses the concept of soil in both urban and rural environments to illustrate the obvious need to increase our understanding of urban soils. The first section describes spatial variability of the urban soil system. Recent directions in classification of urban soils through the Anthrosol and Regosol major soil groups (ISSS-ISRIC-FAO, 1994) are presented in the second section to show the current trends and to illustrate how the classification of urban soils is essentially undeveloped. In the third section, models of soil genesis are discussed to understand the processes and functions of the soil system. This section explores the array of potential human influences on soils, particularly those from urban uses, and proposes that human activities should be considered as a factor of soil formation. A conceptual model using Jenny's (1941) state factor approach for human impact on soil formation details the ''anthroposequence'' (Pouyat, 1991; Amundson and Jenny, 1991). The anthroposequence model is a conceptual analog to ''toposequence and chronosequence models'' and may be applied for studying soil systems along the urban-rural land use gradient (Pouyat, 1991). The pedologic process of ''anthropedoturbation'' is supported as a mechanism to quantify the role of human activity in changing the ''natural'' direction of soil formation (Fanning and Fanning, 1989). Other models of soil formation are reviewed to illustrate significant spatial and temporal impacts from human activity as an important genetic process. The final section identifies future directions of soil science research in the urban-rural landscape such as detailed soil mapping, revisions to current soil classification systems, and characterization of benchmark anthroposequences.

The concept of urban soil

The pedologic definition of soil is ''a collection of natural bodies on the earth's surface, *in places modified or even made by man of earthy materials,* containing living matter and supporting or capable of supporting plants out-of-doors'' (Soil Survey Staff, 1975). This definition of soil is used by the United States National Cooperative Soil Survey in its nationwide program to identify and map the locations of soils. The definition of urban soil is conceptually similar to the USDA definition with additional emphasis on the role of nonagronomic human activities. Craul (1992), modified the definition of Bockheim (1974), and defined urban soil as ''a soil material having a nonagricultural, man-made surface layer more than 50-cm thick, that has been produced by mixing, filling, or contamination of land surfaces in urban and suburban areas.'' Hollis (1991) defined urban soil as ''Any unconsolidated mineral or organic material at the Earth's surface that has the potential to support plant growth.'' Hollis's definition identifies regions of urban soil that may be potentially toxic to plant growth (Fanning *et al.,* 1978) but must be addressed in an urban soil classification system.

All three definitions of soil or urban soil indicate that some amount of anthropedoturbation is evident in the soil profile. Urbanthro-pedoturbation is defined as any human-initiated, *nonagronomic* activity that influences the composition and genesis of soil. This definition is more restrictive than the ''anthropedoturbation'' of Fanning and Fanning (1989), which also considered agronomic impacts such as the physical mixing of the soil by plowing or cultivation.

The areal distribution of ''natural'' or undisturbed (or minimally disturbed) soil varies inversely with respect to the extent of urbanization. For highly urbanized areas, the spatial distribution of undisturbed ''natural'' soils is limited to ''patches'' of the land surface, which frequently possess unsuitable soil characteristics for urban development such as wetness, flooding, rockiness, or unstable slope configuration. In urban metropolitan areas, the density of undisturbed soils typically increases, moving from the highly developed core to suburban and rural areas, or ''the urban-rural land use gradient'' (McDonell and Pickett, 1990; Pouyat, 1991).

Nonagronomic human activity affects soil genesis and associated soil characteristics in various combinations determined by both the rate and extent of disturbance. Human activities such as surface mining, deposition of dredge spoils, and highway construction rapidly and dramatically alter both the direction and extent of soil forming processes (Fanning and Fanning, 1989). In contrast, additions of earthy fill materials (excavated from either natural or disturbed soils) or human-derived artifacts (e.g. broken bricks and glass, ashes, crushed stone) during housing construction may influence the rate and extent of soil formation across a wide range from the limited effects of minimal fill placement to marked soil disturbance from excavations of foundations.

Spatial variability of urban soils

The commonly observed variability of urban soils indicates the extent of nonagricultural human disturbance and our limited knowledge of the processes that influence urban soils. Craul (1992) discussed urban soil variability in the context of vertical and spatial (horizontal) variability. Vertical soil variability is observed as soil horizon differentiation or lithologic discontinuities in both undisturbed and disturbed soils. In urban soils, short-range vertical and lateral changes in soil horizonation result from human activities such as excavation and subsequent backfilling. Spatial variability can be separated into systematic and random variation with both the scale of observation and our current knowledge base determining the distribution of each component (Wilding and Drees, 1983). Nonagricultural human activity contributes to soil variability through systematic variation such as replanting of a stream corridor to create riparian buffer zones, and roadway construction altering topography through sequential cut-and-fill operations. Random variation may be expressed as a result of differential erosion and sedimentation rates associated with land development activities. It is conceivable that most random variation in urban soil landscapes simply reflects our present limited level of knowledge. As knowledge of the interaction between nonagronomic human activity and urban soil characteristics increases, random variation may be identified as systematic soil variability (Wilding and Drees, 1983).

Spatial variability of urban soils is implied in modern soil survey reports for urban areas by the identification and mapping of ''Soil Series-Urban land complexes.'' The soil series, or the lowest level of the USDA soil classification system, is identified as a basic sampling unit or pedon and mapped as the geographic unit or polypedon. ''Urban land'' is defined as ''soil covered by fill material to a depth of 18″ or more, or all or most of the soil has been cut away'' (Reybold and Matthews, 1976). The transition between the ''undisturbed'' soil and ''Urban land'' are unnamed components of the soil complex. The relative percentage of the three components (undisturbed soil, transition, and ''urban land'') varies based on the historical impact of nonagronomic human activities such as grading and cut-and-fill operations (Table 1). Spatial variability occurs within both the natural soils (Baltimore and Beltsville series) and the human-influenced regions (''Urban land'') of the soil map delineations.

Figure 1 shows the distribution of Urban land for Maryland based on analysis and mapping of the State Soil Geographic (STATSGO) Data Base published by the US Department of Agriculture Natural Resources Conservation Service (1994). The STATSGO data were compiled at a map scale of 1:250 000 and are intended for broad land use resource planning, management, and monitoring. In Maryland, the STATSGO data for Urban land were compiled with the area of each soil polygon ranging from 0 to 10 percent Urban land. The Urban land map clearly illustrates regional urbanization associated with the Baltimore, MD-Washington, DC region. Additional regional urbanization is displayed in central Maryland (Howard, Montgomery and Carroll counties), sections of the Frederick and Hagerstown valleys (Frederick and Washington counties), and adjacent to the Potomac River near the towns of Hancock and Cumberland (Alleghany county). The STATSGO data are useful for examining the urban-rural gradient

Table 1. Selected Examples of Urban Soil Map Units in Baltimore County, MD (Reybold and Matthews, 1976)

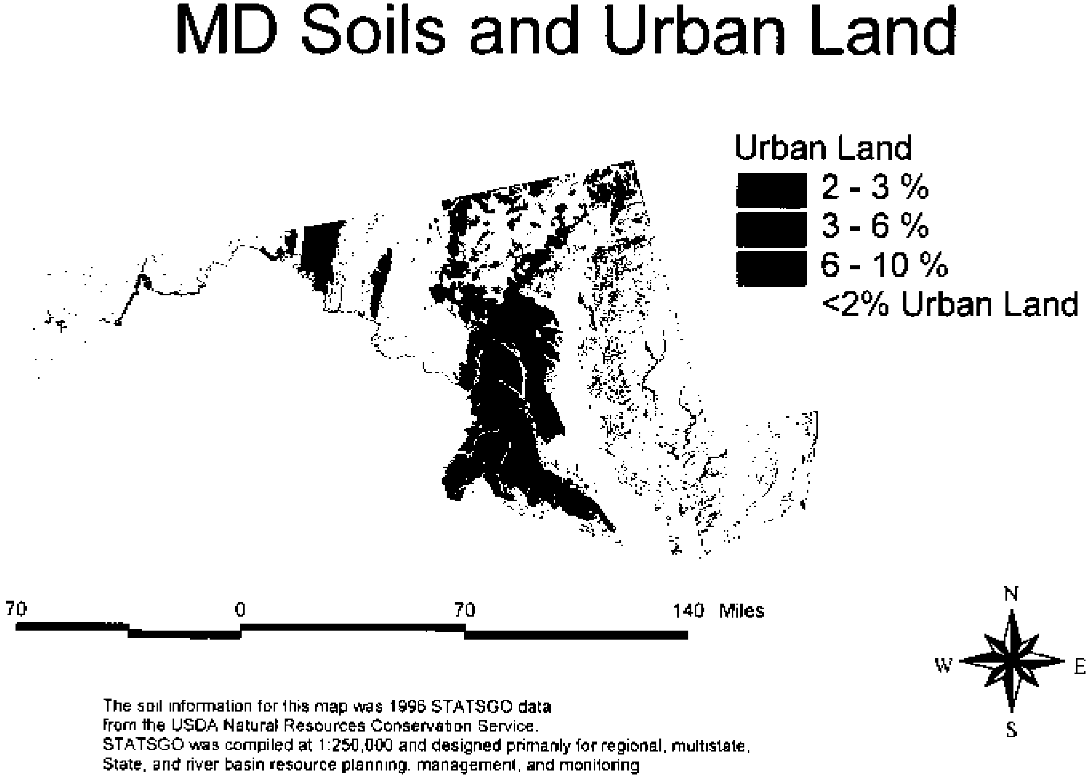
Baltimore-Urban land complex (0–8% slopes)	This complex consists of level to gently sloping soils of the Baltimore series that have been cut, filled, graded or otherwise disturbed by nonfarm uses. This complex generally is in areas where suburban development has expanded into parts of fertile limestone valleys. In about 40 percent of the area of this complex the soils are relatively undisturbed. In about 50 percent of the complex the soils have been covered by as much as 18 inches of borrow material or other fill, or they have had as much as two-thirds of the original profile removed by cutting or grading. The remaining 10 percent of the area is Urban land where soils have been covered by 18 inches or more of fill material, or most or all of the soil material has been removed by cutting or grading. The fill material is variable but is generally from adjacent areas of Baltimore soils that have been cut or graded.
Beltsville-Urban land complex (0–5% slopes)	This complex consists of soils of the Beltsville series, half of which have been cut, filled, graded, or otherwise disturbed for nonfarm uses. These soils are in the southeastern part of the county in areas where residential and industrial development is expanding. About 50 percent of any area in this complex consists of relatively undisturbed Beltsville soils. These soils have a surface layer of loam or silt loam and in places are gravelly. In about 40 percent of the area the soils have been covered by as much as 18 inches of fill material or about two-thirds of the original soil has been removed by grading or cutting. The remaining 10 percent is Urban land where the soil has either been covered by more than 18 inches of fill material or has been mostly or entirely cut away. The fill material is variable, but generally it is from adjacent areas of Beltsville soils that have been cut or graded. Streets and buildings are in parts of this complex.

because the scale of observation offers a regional perspective, and multistate analysis of soils information can be conducted. Data reported as ‘‘variable’’ or not listed in the soil attribute files suggest limitations with using STATSGO data on urban lands. In part, these limitations occur from soil variability and from minimal application of nonagronomic human activities as a process of soil formation in the USDA soil classification system *Soil Taxonomy* (Soil Survey Staff, 1975).

Soil classification and mapping of urban areas

The soil classification system organizes complex data for a large number of soil variables into groups or classes as a method to both simplify and communicate information for mapping, interpreting, and managing the soil resource. In addition to the US soil classification system and other national systems, the International Soil Science Society, International Soil Reference and Information Centre, and the Food and Agriculture Organization of the United Nations recently drafted a ‘‘World Reference Base for Soil Resources’’ for discussion and comments (ISSS-ISRIC-FAO, 1994). This draft of the world soil resource system is intended to provide common terminology for various activities such as monitoring the development of soils in regions where both agricultural and nonagricultural human activities occur, and the transfer of technological innovations across regions. Furthermore, the World Reference Base is intended to function as a tool for the correlation of soils among the many national systems and the FAO’s Revised Legend of the Soil Map of the World (1988) and is not proposed as a new soil classification system to replace the present national systems (ISSS-ISRIC-FAO, 1994).

The World Reference Base considers human activities (agronomic and nonagronomic) in the Anthro-



The soil information for this map was 1996 STATSGO data
from the USDA Natural Resources Conservation Service.
STATSGO was compiled at 1:250,000 and designed primarily for regional, multistate,
State, and river basin resource planning, management, and monitoring

Figure 1. Maryland soils and urban land (USDA/NRCS, 1996).

sols and Regosols major soil groupings. The Anthrosols soil class was introduced in the FAO's Revised Legend of the Soil Map of the World (1988) for soils ''in which human activities have resulted in profound modification or burial of the original soil horizons, through removal or disturbance of surface horizons, cuts and fills, secular additions of organic materials, long-continued irrigation, etc.'' (ISSS-ISRIC-FAO, 1994). The dominant soil-forming process for Anthrosols is ''anthropedogenesis'' (Kosse, 1990). Specific examples of anthropedogenic processes include deep, continuous mechanical operations, intensive fertilization, additions of extraneous materials, additions of sediment-rich irrigation water, and wet cultivation. The proposed definition emphasizes (1) lack of recognition of the original soil, or (2) identification of the original soil as a ''buried soil'' (depth > 50 cm). The anthropedogenic processes recognize unique soil forming processes that result in anthropedogenic horizons. This definition suggests that ''a sustained period of pedogenesis'' is required to sufficiently form Anthrosols from disturbed soils.

Significant soil-related human activities such as mining, dredging, and filling are considered ''anthropogeomorphic'' processes (Kosse, 1990). These activities result in earthy material that has not undergone sufficient time periods for expression of pedogenesis based on field examination. In certain environmental settings (e.g. sulfidic dredge materials from the Baltimore Harbor and Chesapeake Bay), rapid soil structure development and soil horizonation were observed within a few months following dredge deposition (Fanning and Fanning, 1989). ''Anthropogenic soil materials'' are ''unconsolidated mineral or organic material'' created by landfills, mine spoil, urban fill, garbage dumps, dredgings, and other human activities (ISSS-ISRIC-FAO, 1994). Specific examples of anthropogenic soil materials (modified from Fanning and Fanning, 1989) include ''Garbic,'' or landfills dominated by organic waste products;

''Spolic,'' or earthy materials from industrial activities (mine spoil, dredging, highway construction); and ''Urbic,'' or earthy materials containing greater than 35% (by volume) human artifacts and building rubble (ISSS-ISRIC-FAO, 1994).

The World Reference Base proposes the Regosols major soil grouping for ''recently exposed, earthy materials at the earth surface'' (ISSS-ISRIC-FAO, 1994). The Regosols major soil grouping uses the genetic soil classification approach to identify soils that are ''very weakly developed'' and thus do not exhibit soil characteristics from ''normal'' pedogenic processes. The time factor of soil formation is not significant for this major soil grouping and the soil characteristics reflect the mode of parent material accumulation and the inherent (unweathered) properties of the parent material. The Anthropic Regosols soil unit is proposed for soils that have anthropogenic soil materials or were extensively modified by human activities. Extensive modifications from human activities range from deep ploughing to surface mining, land filling, dredging, and highway construction. Future soil survey and classification activities should characterize the composition of soils along selected urban-rural land use gradients and modify the current soil classification system to document the impact of human activities on soil formation in urban landscapes.

Models of soil genesis in the urban environment

The continued growth of human populations and the uncontrolled spread of urban areas worldwide makes our understanding of human influences on soils increasingly important. Processes of soil formation that are altered by human activity (described above) are considered to be deviations from the normal, and as a consequence, changes in soil characteristics resulting from human intervention are not applicable to the current soil taxonomy (Yaalon and Yaron, 1966). *Soil Taxonomy* does consider human influences on soil processes from agricultural activities through the development of plaggen and anthropic epipedons and the agric horizons (Soil Survey Staff, 1975).

Human influences on soils can be very complex, with many interactions occurring between anthropogenic and natural processes of soil formation (Bidwell and Hole, 1965). A conceptual model provides a simple way to express these relationships and explore the various ramifications that human activities have on soil formation. Models of soil formation or genesis help identify the processes of soil formation that may be altered by human activity (Smeck *et al.,* 1983). This conceptual modeling may improve our classification, interpretation, and management of soils that are disturbed by human activity. This section describes Pouyat's model and additional conceptual models of soil genesis to illustrate the importance of nonagronomic human activity on soil formation.

A state-factor model of soil genesis

Soils are considered as a collection of organized natural bodies with characteristic horizons that develop from pedogenic processes (Fanning and Fanning, 1989). The characteristics of soils are determined by a combination of factors that include climate (cl), organisms (o), parent material (pm), relief (r), and time (t), where a characteristic of any given soil, S, is the function $S = f(cl, o, pm, r, t)$ (Jenny, 1941).

The factor approach provides a systematic way to examine relationships among soils (Fanning and Fanning 1989), as will be discussed later, and helps to conceptualize the role humans play in soil formation. Human influences can be incorporated in the factor approach in two ways: first, humans can be considered on an equal basis with other living organisms, and second, humans can be considered independently of other organisms (Fig. 2), necessitating the inclusion of a sixth, anthropogenic factor (a), such that

$$S = f(a, cl, o, pm, r, t). \tag{1}$$

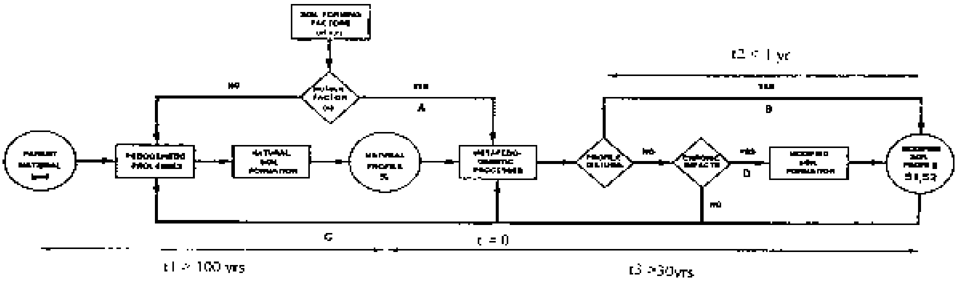


Figure 2. Schematic model of soil genesis. Symbols are explained in the text.

Pouyat (1991) proposed that human influences necessitate the inclusion of a separate factor because humans, unlike other organisms, are purposeful manipulators of soils (Bidwell and Hole, 1965). Furthermore, human effects on soils occur on different spatio-temporal scales than those of other organisms, primarily because of the use of technology by humans. Technology has supported an exponential increase in human population growth and has increased the extent and magnitude of our disruption of the landscape (Ehrlich *et al.,* 1976).

The conceptual model of soil-forming factors was described by Dokuchaev in 1879 and Hilgard in 1892 (Arnold, 1983). In 1941, Jenny proposed the factoral model of soil genesis as a mathematical expression in which each factor acted independently of the others such that the manipulation of one factor does not affect another. Likewise, the anthropogenic factor can act independently of the other factors. For example, if a human-induced catastrophic event occurs in which the soil profile is disrupted, the human impact on that soil occurred independently of the other soil forming factors. In this case, however, the temporal scale of the human modification is much shorter than the time frame in which most natural pedogenic processes operate. Here the natural profile (S in Equation 1) predating the "new" modified profile (S_2) can be considered the "new" pm, so that

$$S_2 = f(a, cl, o, S, r, t). \tag{2}$$

Essentially, there is a new time zero from which soil genesis takes place.

Factors of soil formation can also be interdependent (Jenny, 1980; Fanning and Fanning, 1989), particularly when human influences occur over time scales similar to natural soil formation. Under such conditions, interactions with other factors are more likely, e.g. the potential effect of acid deposition on transformation processes in the soil. Here the natural profile remains essentially intact, although various chemical and physical properties may be altered through human interactions with natural soil formation, and the pm remains constant, such that

$$S_1 = f(a, cl, o, pm, r, t). \tag{3}$$

The model distinguishes between natural soil forming processes (pedogenic) and human soil forming processes (anthropedogenic or metapedogenic). Yaalon and Yaron (1966) proposed the use of the term "metapedogenesis" to differentiate natural pedogenic processes from human-induced processes. Metapedogenic processes have occurred only recently relative to geologic time scales and, according to Yaalon and Yaron (1966), act primarily after natural soil profiles have formed, thus the prefix meta.

Pedogenic processes are classically defined by pedologists as the soil forming processes of weathering, organic matter breakdown, translocation, and accumulation (Brady and Weil, 1996). Fanning and Fanning (1989) more specifically regard these as "narrow" processes in comparison to "gross" processes of soil formation. A gross process constitutes a suite of narrow processes working together over time, e.g. the podzolization of forest soils.

In introducing their concept of metapedogenesis, Yaalon and Yaron (1966) give examples of what Pouyat (1991) considered gross metapedogenic processes, including various human activities such as cultivation and deforestation. It is important, however, to understand the nature of the narrow processes that make up these gross processes. Pouyat (1991) suggested that the following narrow processes of metapedogenesis be recognized: (1) mixing or anthro-pedoturbation (*sensu* Fanning and Fanning, 1989); (2) compaction; (3) addition of chemicals or materials; and (4) removals of chemicals and materials. These narrow processes of metapedogenesis are by definition unique to human activity, e.g. anthro- is distinguishable from faunal-pedoturbation, and are only apparent when the human factor dominates in soil formation. The conceptual approach to incorporating metapedogenesis into soil formation relies heavily on Jenny's (1941) classic soil forming factors. In the schematic diagram of the model (Fig. 2), the pm of the soil represents the initial state of the model. The soil forming factors of cl, r, and living o are the driving variables of the model and create an environment in which pedogenic processes take place. The model is sequential with different time scales represented by t1 (long timespans of >100 yr), t2 (short timespans of <1 yr), and t3 (moderate timespans of >30 yr), and having conditional end points, or output variables, of either a natural profile (S), when human influences are absent, or modified profiles (S_1 and S_2), when human influences are dominant. Conceptually, the model is a modified version of Yaalon and Yaron's (1966) model of metapedogenesis in which various metapedogenic processes (m_n) occur in rapid fashion, nullifying the effects of natural soil forming processes, where $S_2 = f(S, m_1, m_2, m_3 ...)$. In the proposed model, the natural soil forming factors function constantly (Equations 1 and 2) and the time scales in which metapedogenesis takes place can be distinguished (t2 and t3 in Fig. 2).

Pedogenesis begins when the pm is exposed to environmental conditions that promote natural soil formation, while metapedogenesis begins when humans become a factor in soil genesis (pathway A in Fig. 2). When the soil profile is rapidly disturbed (pathway B in Fig. 2), soil genesis begins at a new time zero (Equation 2). Because such a disturbance is episodic, with time, pedogenic processes can again dominate if metapedogenic processes are removed and a natural profile becomes reestablished (pathway C in Fig. 2).

At time scales similar to natural soil formation, metapedogenesis is likely to work in combination with pedogenic processes (Equation 3), and thus are interdependent, resulting in less conspicuous changes in soil properties. In this scenario, soil stress results in a different trajectory for soil formation over time t3 and eventually a modified soil profile (S_1) is established (pathway D in Fig. 2). Here, metapedogenic processes change the intensity of pedogenic processes and there is a resultant change in soil formation.

The model represents a conceptual framework of soil genesis that incorporates metapedogenic processes that can be used to delineate alternative outcomes of soil development. The model has three generalized outcomes:

1. Natural profiles form under natural conditions of soil genesis (S in Fig. 2);
2. Modified profiles form under natural conditions, but are then modified by human influences so that distinctive characteristics evolve from the natural profile (S_1 and S_2 in Fig. 2). Modified profiles can be differentiated by the duration of the metapedogenic processes that produce them. These are: (1) profiles formed by a disturbance over short intervals of time (t2), e.g. cut and fill; and (2) profiles formed by a stress over longer periods of time (t3), e.g. agric horizons formed by continuous cultivation (Fanning and Fanning, 1989);
3. Quasi-natural profiles form under natural conditions and are later influenced by metapedogenesis, but for various reasons do not develop distinguishing morphological characteristics from metapedogenesis. Quasi-natural profiles are not endpoints *per se* in the model, but are transition phases of the profile outcomes discussed above. Quasi-natural profiles include situations where: (1) enough

characteristics remain so that the original soil profile is recognizable, e.g. the Arent suborder (Fanning and Fanning, 1989); (2) enough time has passed from when the profile was modified so that natural horizon development may occur, e.g. cambic horizon development in fill (Short *et al.*, 1986a,b); or (3) metapedogenic processes do not cause a change in morphological characteristics but rather cause a change in measurable soil physical or chemical properties, e.g. chemical changes caused by acid deposition (Ulrich *et al.*, 1980).

These generalized outcomes of profile development and changes in soil properties from specific human influences have important taxonomic and practical implications. The model can yield information useful for delineating soil taxonomic units of human modified soils, which is a critical step in the development of a classification system. In addition, the model has practical significance to planners and natural resource managers because deleterious effects from human activities, i.e. differences between S and S_2 in Equation 2, can be predicted and potentially avoided.

These changes in characteristics of soil profiles as conceptualized by the model of soil genesis can be described and studied in a systematic way using the urban-rural gradient as a template in which to apply Jenny's (1941) factor approach. As a case in point, preliminary results from studies of undisturbed forest soils along an urban-rural gradient in the New York City metropolitan area indicate that soil levels of lead, copper, and nickel increase rapidly over relatively short distances (1 to 100 km) going from rural to urban stands (Pouyat and McDonnell, 1991). This relatively steep gradient of heavy metal deposition allowed the location of study sites on similar soil and vegetation types. Therefore, when the human factor is in operation (in this case an addition of chemicals), as in Equation 1, the urban-rural gradient can provide situations wherein the anthropogenic factor varies over relatively short distances, whereas the remaining factors are held constant, i.e. an ''anthroposequence,'' where $S = f(a)_{cl,o,pm,r,t}$.

Anthroposequences can be used to make direct comparisons of the effects of human influences on soils. As was previously established, modified profiles in the landscape come about when the soil profile is acutely disturbed or when stress eventually causes a change in profile characteristics. In the former case, modified profiles can be viewed as new pedogenic situations expressed as $S_2 = f(a,cl,o,S_1,r,t)$ and in the latter case soil development occurs under new environmental situations expressed as $S_1 = f(a,cl,o,pm,r,t)$. Therefore, there are two metapedogenic situations, differentiated by temporal scales, in which anthroposequences can be defined and used for investigation. Where $S_2 = f(a)_{cl,o,S_1,r,t}$, direct comparisons of different soil disturbances are possible between soils developing under similar environmental situations. Furthermore, under such conditions, recovery processes can be compared between disturbance types. Where $S_1 = f(a)_{cl,o,pm,r,t}$, long-term influences on soil formation can also be studied over similar soil types. Such comparisons will be particularly useful in delineating threshold responses of soil properties to stress from the deposition of atmospheric pollutants.

Energy model for urban soils

A refinement to Jenny's (1941) five state-factor model was proposed by Runge (1973) to emphasize three factors: water available for leaching (w); organic matter production (o); and time (t).

$$S_{energy} = f(w,o,t)$$

Organic matter production is correlated with Jenny's (1941) parent material and vegetation factors, and water available for leaching roughly equals climate and relief factors (Smeck *et al.*, 1983). This model visualizes soil as a ''chromatographic column'' in which soil development is affected by energy fluxes and changes in entropy of ''disorder'' based on a thermodynamic approach.

The influence of nonagronomic human activity on soil hydrology and biogeochemical cycles along the urban-rural environmental gradient could be examined by applying a modified form of the ''energy model.'' Human activities are known to alter organic matter production and water available for leaching in most terrestrial environments. Further refinements to the ''energy model'' should also incorporate lateral fluxes (Smeck *et al*., 1983).

A systems approach to model soil genesis along the urban-rural gradient

The earliest systems approach (or process-response model) for soil formation was suggested by Simonson (1959) to address mechanisms of soil development that are not explicitly described by factoral models such as Jenny's (1941) five factors. Simonson suggested soil formation results from two basic steps: (1) parent material accumulation; and (2) horizon differentiation. Development of soil horizons is caused by four primary processes: (1) additions; (2) losses; (3) transfers; and (4) transformations, that were generalized to encompass all known and unknown specific processes. Parent material accumulation commonly results from geologic and geomorphic processes. This model may be coupled with quantitative modeling of the specific processes that are ordered by relative importance to estimate soil development.

The ''valley basin'' or ''soil-landscape system'' of Huggett (1975) provides three-dimensional functional boundaries for modeling the fluxes of matter and energy in the urban-rural environmental gradient. Conceptually similar to a watershed, the soil-landscape system is bounded by drainage divides, the pedosphere-atmosphere interface (land surface) and the pedosphere-lithosphere interface (weathering front at the base of the soil profile; Smeck *et al*., 1983). This model sufficiently ''compartmentalizes'' the soil to determine mass and energy balances in ecological systems.

Future directions of soil science research in urban landscapes

Human influences on soils are very complex, with many interactions occurring between human, or anthropedogenic, processes and natural pedogenic processes of soil formation. The spread of urban centers into forested landscapes and the increasing level of chemical inputs into forest ecosystems necessitate the inclusion of anthropogenic factors of soil formation in our concept of soil genesis. Rapid changes in the nature and intensity of human influences on forest soils occur along urban-rural land use gradients and provide an excellent opportunity to study human modifications of soils.

The spatial variability of soil characteristics and morphological features along the urban-rural land use gradient should be examined at various scales of observation. Historically, soil mapping for agricultural lands depended on intensity of land use with mapping typically at scales ranging from 1:15 840 to 1:24 000. Current technological advances (i.e. Global Positioning Systems, Ground Penetrating Radar, satellite imagery) and intensive urban land use require modern soil surveys at large map scales such as the 1:6000 scale used for engineering and site assessment by the recently closed Fairfax County, Virginia Soil Science Office or the 1:12 000 scale applied for modern soil survey revisions of various Maryland counties. Arnold (1983) proposes that current soil science theory has not yet agreed on a unified fundamental concept of soil as a ''geographic body''; however, map scales of 1:6000 to 1:12 000 may offer a level of cartographic detail with ''reasonable agreement of such units among field-soil mappers.''

High-intensity (i.e. large scale) soil characterization and mapping in selected *benchmark anthroposequences* is proposed as a reference data source to effectively study the urban-rural land use gradient. A more comprehensive soil classification system that considers soils significantly influenced by nonagronomic human activity should be developed as a component of this project. Recently, an international committee addressing the classification of anthropogenic soils (ICOMANTH), chaired by R. B. Bryant, Cornell University, initiated activities to develop proposals revising *Soil Taxonomy* with respect to human effects on soils. Testing of the modified or new soil classes would be examined in other urban areas. Coincident with the study of *benchmark anthroposequences* in selected urban-rural landscapes, models of soil formation should be modified to include nonagronomic human activities that influence soil processes. As the conceptual models of soil formation evolve to quantitatively replicate soil forming processes, the impact of nonagronomic human activity on soil formation and distribution can be quantified and incorporated in the new models.

Traditionally focused on agricultural land evaluation, urban land planners and resource managers are requesting that modern soil survey programs document the soil resources for improved interpretation and management. A multidisciplinary, intergrated study along the urban-rural land use gradient is needed to improve our knowledge of the spatial relationships of urban soils. Increased knowledge of these spatial relationships will allow better predictive modeling of urban ecosystem functions and thus contribute to more accurate land use interpretations and management of our limited ecological resources.

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