The Perfect Soil

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Abstract

Soils are products of interacting influences of multiple environmental controls, combining in specific geographical/historical contexts to produce highly improbable (i.e., unlikely to be duplicated) outcomes. Soil systems also have multiple degrees of freedom in responding to environmental influences, thus allowing for many possible soil system states. The "perfect storm" metaphor describing the improbable coincidence of several different factors to produce an unlikely outcome has been applied to geomorphology in the perfect landscape concept. This concept can be further extended to soils. The joint probability of any specific set of global soil-forming factors is low, as the individual probabilities are < 1, and the probability of any set of local, contingent factors is even lower. Thus, the probability of existence of any soil or soil system state is negligibly small: all soils are perfect. Application of the perfect landscape concept to soils is inconsistent with a worldview holding that soils are inevitable outcomes of deterministic laws, such that only one soil is possible for a given set of laws and initial conditions. Rather, a perfect soil/landscape perspective leads toward a worldview that soils are circumstantial, contingent results of deterministic laws operating in specific environmental contexts, such that multiple outcomes are possible.

Key Words

Perfect soil, perfect landscape, contingency, soil geomorphology, soil geography

Introduction

The "perfect storm" has come into wide use as a general metaphor for the improbable covergence or coincidence of several events or factors to produce an unusual outcome since publication of a popular book (Junger, 1997) and subsequent film by that title. Junger (1997) used the term to refer to a rare covergence of synotpic systems to create an extremely unusual meteorological event, and popular use of the metaphor often connotes troublesome of disastrous outcomes. Phillips (2007), however, adapted the metaphor to geomorphological landscapes, arguing that as results of combined, interacting effects of environmental controls that include local historically and geographically contingent factors (as well as universal or general laws or relationships), landscapes are "perfect."

This perspective is perhaps even more readily applied to pedology. The soil-landscape paradigm and the factorial model of soil formation are tracable to the "clorpt" model of Jenny (1941) and the seminal pedological works of Dokuchaev (1883). Soils are seen as the product of the cumulative, interacting influences of climate (*cl*), organisms (*o*), topography or relief (*r*), geology or parent material (*p*), and time, so that the nature of soil (*S*) is a function of these factors: $S = f(cl,o,r,p,t) \ldots.$ The "clorpt" factors represent those which are always relevant, and the trailing dots other factors which may be locally important. The geographically-specific, temporally contingent combined impact of multiple controls, and the presence of both global and lcoal controls are explicit in this conceptual framework from its inception. Adaptations and interpretations in recent decades have further recognized the mutual interactions among the soil forming factors and soil themselves, and the fact that any given factor may itself have global and local aspects (see e.g., Phillips, 1989; Johnson and Hole, 1994; Schaetzl and Anderson, 2005).

Few pedologists would claim that any two soils are identical in minute detail. The perfect soil concept goes beyond this axiomatic point to argue that explaining and understanding soils necessitates an integration of local, contingent, historical explanation with deterministic, nomothetic explanation based on universal principles. This paper will argue that, in addition to the multiple environmental controls in geographical and historical context explicit in the factorial model, soils exhibit the other characteristics of perfection in the sense above:

- Multiple degrees of freedom in responses to environmental change.
- Geographical and historical contingency, sometimes exacerbated by dynamical instability.
- Low joint probabilities of any given set of global and/or local controls.

Elements of Perfection

Multiple Degrees of Freedom

Even where soils are influenced by the same set of environmental forcings, multiple degrees of freedom may mean that more than one response is possible (even in the qualitative sense, as opposed to quantitative details). The effects of relative sea level rise on coastal marsh soils, for instance, may trigger responses in mineral accretion, organic accretion, compaction, soil salinity, and surface and fringe erosion, among other things. This in turn leads to a variety of aggregate responses, including landward migration and encroachment on adjacent uplands, drowning or erosion in place, fragmentation, and various combinations of these. Highly localized factors such as surface microtopography, vegetation and litter dynamics, proximity to tidal channels and pools, and topography of adjacent uplands influence the responses, resulting in a variety of idiosyncratic responses, sometimes within a relatively small area (see, e.g., Gardner *et al.*, 1992; Phillips, 1992; Reed, 2002).

The response of semiarid soils to overgrazing, for another example, is often dichotomous. Rather than relatively spatially consistent surface changes, divergence occurs into nutrient-rich, vegetated patches with little erosion, and bare, eroded, nutrient poor patches. The local variability of these multiple responses is sometimes exaggerated by dynamical instability and deterministic chaos, such that minor initial variations are increasingly magnified over time (see, e.g., Phillips, 1993; Monger and Bestelmeyer, 2006).

Contingency

Historical contingency in soils is well known in the form of inherited or relic features, and conditionality. The latter occurs when pedogenesis may proceed along two or more different pathways, according to the (non)occurrence of a particular event or phenomenon, such as fires or glaciations. Johnson and Watson-Stegner (1987; see also Schaetzl and Anderson, 2005) give examples of how soils might follow regressive or progressive pedogenetic paths according to whether or not specific events occur. Dynamical instability or chaos may also lead to historical contingency, as persistent effects of small disturbances lead to soil memory (e.g., Phillips and Marion, 2004).

Joint Probabilities

Any given soil is influenced by *n* general state factors *G* reflecting universally or at least very widely applicable influences associated with a particular climate setting, lithology, etc., whenever and wherever it might occur. The soil is also affected by *m* contingent state factors *L* reflecting local particularities. The same state factor might have both *G* and *L* aspects. For instance, limestone parent material will result in some aspects of soil which are common to all limestone-derived soils, and some which are particular to the geochemistry, mineralogy, and structure of, e.g., the Lexington Limestone formation. The probability of occurrence on any given specific soil is a function of the joint probabilities of the *G* and *L* factors:

$$p(S) = \prod^{n} p(G_i) \prod^{m} p(L_j),\ \ p(G_i), p(L_j) < 1, \qquad (1)$$

The probability of any given $G_i < 1$, and by their very nature, $p(L_j) << 0$. Thus $p(S) << 1$.

Implications

The basic components of the perfect soil concept are that (1) soils are strongly influenced by laws, principles, and relationships that are independent of location and time, and that apply within their domains everywhere and always (*G* factors); (2) soils are strongly influenced by geographically and historically contingent factors particular to place and time and thus idiosyncratic *(L* factors); and (3) the probability of a specific set of *G* and *L* factors at a given place and time is extremely low; thus soils have elements of uniqueness. While some particular problems in pedology can be solved based entirely on *G*-factors, in general the significance of *L*-factors is irreducible. That is, no amount of data, detail, or model refinement can eliminate the role of geography and history. In fact, eq. (1) indicates that inclusion of more details—adding *G* or *L* variables—must decrease the generality of results.

Divergent Evolution

The importance of local contingencies and the role of dynamical instabilities suggests that in many cases soil landscapes may undergo divergent evolution, whereby the soil cover becomes increasingly differentiated. This is in contrast to classical notions of convergent evolution toward mature, zonal soils characteristic of regional climatic zones.

A simple example is given by soil thickness in the Ouachita Mountains, Arkansas. *G*-factors associated with the "clorpt" factors at a regional scale determine the broad population of soils found in the region, and *G*-factors associated with topographic relationships, microclimate (i.e., slope aspect), and parent material create some systematic variations in thickness at a more local scale. Nonetheless, major variations in thickness exist within small plots unrelated to topography and lithology. These are instead associated with effects of individual trees, such that vegetation history is an important explanatory variable at the hillslope scale, and self-reinforcing pedologic influences of trees create divergent evolution at the patch scale (Phillips and Marion, 2004; 2005; Phillips *et al*., 2005).

Concluding Remarks

The perfect soil concept leads to a worldview based on the notion that soils are circumstantial and contingent results of general laws and principles operating in specific environmental and historical contexts. A given soil is only one possible outcome of a given set of processes, initial, and boundary conditions, which is partly determined by a particular, irreproducible set of contingencies. However, the pedological outcomes are strongly constrained by the applicable general rules and relationships. While it is often legitimate and useful to conduct soil research based on either global, general *G*-factors or local, idiosyncratic *L*-factors, the ultimate goal of explaining pedogenesis and soil variability requires the integration of these approaches.

A perfect soil worldview stands in contrast to traditional soil science reductionism, and to equilibrium as a normative (rather than a possible or reference) state, though it does attempt to integrate deterministic, nomothetic, process-based pedology with historical and interpretive pedology. The notion of irreducible contingency may be bothersome to some soil scientists—most of us were trained to strive towards explanation based entirely on general principles, with recourse to local particularities only as a last resort. However, soil perfection also implies numerous opportunities and possibilities for unravelling the stories the soil can tell.

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