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Recent discussions on energy-based pedogenic models by Field and Minasny (2008) and Rasmussen (2008) are timely and important. I wish to add a few points to such a stimulating discussion. I believe this would benefit the community in forging a unified concept about quantitative soil formation and soil functions.

The similarities and differences in the energy models formulated by Volobuyev (1964) and by Rasmussen et al. (2005) can be clarified by the change in internal energy (ΔU) of a soil system during pedogenesis. Related to ΔU is a soil’s thermodynamic entropy (S) that can be interpreted as a measure of a system’s disorder or randomness. Quantification of S in pedogenesis may offer another useful perspective regarding the generation and evolution of soil heterogeneity, soil architecture, and their impacts on diverse soil functions in the environment. The pedogenic models described by Volobuyev (1964), Volobuyev and Ponomarev (1977), and by Smek et al. (1983) presented seemingly contradicting results on soil S, as noted by Minasny et al. (2008). Thus, a clarification on pedogenic S is also needed.

Based on energy balance in the open dissipative system of field soils (Fig. 1), ΔU equals to the net amount of heat added to the system (Qnet = Qin - Qout) minus the work done by the system with available energy (W), plus energy flux associated with net mass transfer into the system (mnet = min - mout):

\[ \Delta U = Q_{\text{net}} - W + (mb)_{\text{net}} \tag{1} \]

where b is specific enthalpy (indicating relative heat contents in the mass). In the energy model of Rasmussen et al. (2005), effective energy and mass transfer (EEMT) is equivalent to Qnet + (mb)net in Eq. [1] (Rasmussen et al., 2009) (which equals to W + ΔU, rather than the total energy entered into the soil system, Qin, as initially indicated by Rasmussen, 2008). This is because EEMT is determined by E_{\text{PPT}} + E_{\text{NPP}} (Rasmussen et al., 2009), where E_{\text{PPT}} = P_{\text{eff}} ΔT c_w and E_{\text{NPP}} = NPP_{\text{bio}} with P_{\text{eff}} being precipitation minus actual evapotranspiration, ΔT being ambient temperature minus 273 (in unit of K), c_w being specific heat of water, NPP being the net primary production of biomass, and E_{\text{bio}} being biomass specific energy content. In other words, E_{\text{PPT}} is the heat flux associated with effective precipitation, and E_{\text{NPP}} is specific productivity of net primary production. Therefore, EEMT essentially quantify the effective transfer of total solar radiation and evapotranspiration to the soil system in the form of heat (E_{\text{PPT}}) and specific productivity (E_{\text{NPP}}).

The energy model of Volobuyev (1964), on the other hand, represents a general accounting of all possible energy sources involved in soil formation, which can be approximated by the total solar radiation input to the soil system (Qin) (called “incoming solar energy on soil formation” by Volobuyev, 1977). Volobuyev (1964) presented Qin = Ra = Re * 1/((1 - α) * T(2/3)) the total solar radiation input to the soil, α is a coefficient of radiant energy, m is a parameter reflecting biological involvement in energy exchange, and K represents moisture available (i.e., ratio of precipitation over potential evapotranspiration). Volobuyev and Ponomarev (1977) presented a variant of Eq. [1]: TΔS = PΔV + ΔG, where T is the soil system’s temperature change (جيلية entropy change during pedogenesis, P is the soil system’s volume change occurred in pedogenesis, and ΔG is the Gibbs (free) energy change—which may be approximated by:

\[ \sum_{i=1}^{k} \mu_i \Delta n_i \]

where μ_i is the chemical potential of soil Component i in the number of moles of Component i divided by the total number of moles, and k is the number of soil components involved in pedogenesis.

In both the models of Volobuyev (1964) and Rasmussen (2005), annual basis of current environmental variables is used in calculations, which implies that E_{\text{PPT}}, E_{\text{NPP}}, Q_{\text{in}} did not change over the time period of pedogenesis. This is true, although some might argue that using current data to infer the past is what we could approximate to reconstruct the past environmental variables of historical data. In calculating G, S, and U for a series of soils, Volobuyev and Ponomarev (1977) used current mineralogical composition and total chemical analysis of soils based on standard thermodynamic data for various minerals. Despite simplified assumption of mineralogical arbitrariness in their calculations, Volobuyev and Ponomarev (1977) found some interesting patterns among different groups of soils, and suggested two characteristic directions of mineral weathering and soil development—one is accompanied by decrease in G and an increase in S (leading to more weathered soils with large quantities of minerals and oxides that reflect higher intensity and more resistance to further weathering, such as Oxisols, Ultisols, and Spodosols), while the other is just the opposite shown by the less weathered soils that are less weathered (such as Vertisols, Histosols, and Humults).