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▶ **To cite this version:**

Vera Leatitia Mulder, Marine Lacoste, Manuel Pascal Martin, Dominique D. Arrouays. Determining land systems of pedogenesis for large-scale soil modelling. 6. Global Workshop on Digital Soil Mapping, Nov 2014, Nanjing, China. hal-02792134

HAL Id: hal-02792134

https://hal.inrae.fr/hal-02792134v1

Submitted on 5 Jun 2020

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Determining land systems of pedogenesis for large-scale soil modelling

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Abstract:

This work aims at determining major land systems having homology in soil-forming factors for supporting large-scale soil modelling. Pedogenesis results from both local and large-scale biotic and abiotic components of the environment. Locally, biological processes, including microbial activity, land management and variability in topography and water availability may render soil formation. Hence, the local variability is embedded within several large-scale biotic and abiotic components, including climatology, geomorphology and surface geology. Large-scale soil modelling within diverse natural environments may be hampered by the intertwinement of local and large-scale environmental components. Within this context, the objective of this work was to partition the surface area covering France into main land systems of pedogenesis and relate their characteristics to soil variability. Here, soil organic carbon (SOC) was used for evaluating the efficacy of land systems in explaining topsoil SOC variability. The land systems were defined by partitioning broad-scale data of climate, land use, parent material and soil type, as supported by the Soil-Landscape paradigm. Data partitioning was done using finite-mixture modelling, a model-based clustering approach, because it was considered an objective and reproducible method for defining clusters having homology in the employed data. Hence, the obtained clusters were deemed to represent typical land systems wherein the major biotic and environmental factors control soil pedogenesis. The exhaustive data was extracted corresponding to the sample locations within the SOC dataset (from the French Soil Monitoring Network and the French Soil Inventory programmes, > 9.000 sites). Subsequently, the difference in SOC content within the different systems was assessed using a Wilcoxon rank-sum test and boxplots. Also, the spatial distribution of the different land systems was evaluated by mapping the sampled sites with its corresponding land system.

The finite-mixture modelling for clustering identified 7 well separated clusters (NEC 0.027). The sampled sites having similar clusters were located closely to each other while the spatial distribution of the different clusters was well defined. The resulting clusters confirmed the expectation that finite-mixture modelling can be used for deriving systems in which the soil forming factors were differentiated. It was found that either climate or parent material was the driving variable defining the systems; subsequently the soil type, followed by a combination of variables capturing land use suitability. In addition, the distribution of SOC content within the clusters deviated from each other and indicated a significant shift ($p < 0.01$) in the mean values compared to the overall mean of topsoil SOC. The SOC dynamics could be

explained by the typical characteristics of the abiotic and biotic conditions of the different systems. Land system 1 typically suffered under severe climatic conditions (temperature, precipitation and events) and shallow, poor soils characterize this system. Systems 2 and 3 were representative for the mountainous areas in France. Considering the major differences between these two clusters, it was found that mainly the parent material caused the separation of the two clusters. System 2 encompassed crystalline and volcanic rocks and sandy materials. It has a substantial difference between summer and autumn precipitation and was strongly influenced by topography. Dense forests dominated the land cover and there was little agricultural activity. Overall, this system was regarded the most natural. The high SOC content corresponding to this system was explained by the substantial coverage of forest and the associated high input of SOC and low turnover rates. On the other hand, system 3 was characterized by calcareous rocks, loamy and clayey materials, little difference between autumn and summer precipitation and fewer extremes in topography. These conditions characterize the system as well suitable for agriculture. Land systems 4, 5 and 6 had similar climatic conditions and the main component separating the clusters was land use. These systems were found to have the lowest SOC content. The rationale behind was the geomorphology and parent material. Cluster 7 covered a large part of France and extended from the Centre plains to northern France. This area was mainly typified as the median of all systems. There was little variability in topography, mixed mineralogy and high nutrient contents. Logically, due to these favorable conditions, this area was dominated by agricultural activities.

The next step of this work entails modelling of soil variability within these large-scale systems; regression models for SOC may be derived using data related to local-scale topography, soil and bedrock properties and meteorological information. By addressing the soil-landscape system as one environment with many dimensions, we may overcome the difficulty of complex biological, chemical and physical processes influencing large-scale soil property modelling. Accordingly, we outlined an objective and reproducible method for understanding large-scale soil processes and variability in soil properties. Also, an interesting and contemporary research topic involves the development of a methodology for quantitative extrapolation of soil information across the globe, also referred to as the Homosoil method. This method assumes homology of soil-forming factors between a reference area, having good legacy data, and a region of interest where soil information is sparse. Globally available data are key for establishing a framework in which the homology of soil-forming factors between areas can be established. Within this context, the finite-mixture modelling approach may be used for (1) deriving specific systems in which soils develop and (2) improve the establishment of homologies in soil-forming factors. Concluding, this work demonstrated the efficacy of soil modelling within major land systems of pedogenesis and its potential for future research. These findings are especially helpful for understanding large-scale soil functioning and are a step forward in modelling soil variability in heterogeneous environments.