Climatic, Topographic, and Land Use Effects on Soil Properties in central Democratic Republic of Congo

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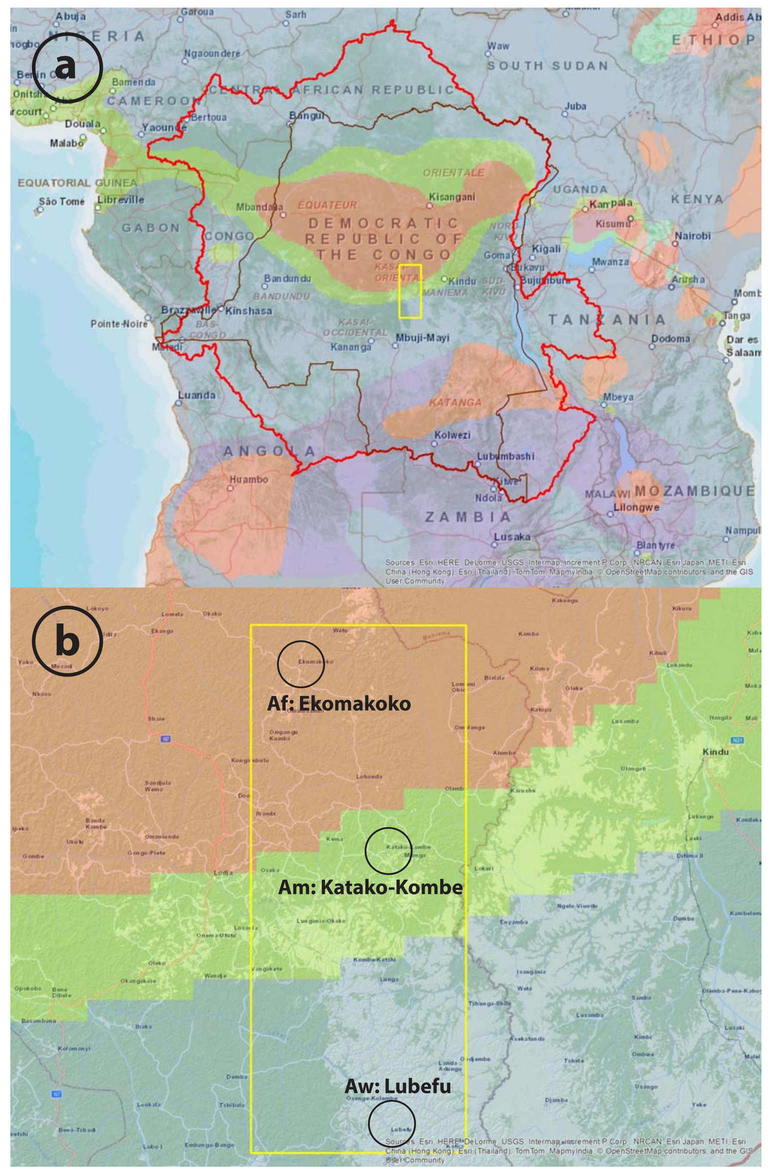

Figure 1. (A) Location of study area within DRC and the Congo River Basin. **(B)** Location of 3 study sites across climatic gradient.

Justification and Approach:

The Democratic Republic of the Congo (DRC) has undergone one of the most significant deteriorations in food security of any African country in the past 20 years (IFPRI, 2015). Paths to sustainable futures for small-holder farmers in DRC includes increasing knowledge of soil properties, particularly highly dynamic properties such as organic carbon, nitrogen and phosphorus, that affect the success of improved agricultural management. Nonetheless DRC continues to be one of the least data-dense countries in the world in terms of soil information, and much of what is known regarding soil properties in DRC comes from only a handful of widely spaced studies, broad estimates, and legacy information from the colonial era (ISRIC, 2014). Understanding how soil properties vary with topography and land-use across climatic zones is a critical foundation that must be established in order to ensure the success of future efforts to improve land use practices, soil health, and food security.

In collaboration with Tshumbe University of Notre-Dame (Lubefu, DRC), our foundational work conducted from August, 2015-January 2016 established 3 sites (Ekumakoko: 2.47°S, 24.03E; Katako-Kombe: 3.39°S, 24.43°E; Lubefu: 4.74°S, 24.44°E) within the study area (Fig 1B). A total of 25 pedons were investigated and sampled across a climate gradient of ~250 km in the central region of the Congo River Basin. This is a critical location because it represents one of the shortest climatic gradients through tropical rainforest (Koppen: Af), tropical monsoon climate (Koppen: Am) and tropical savanna (Koppen: Aw) in DRC. Within each climate zone, soil profiles representing various landscape positions and land-uses were investigated and the effects of these factors on soil morphology and dynamic soil properties were evaluated.

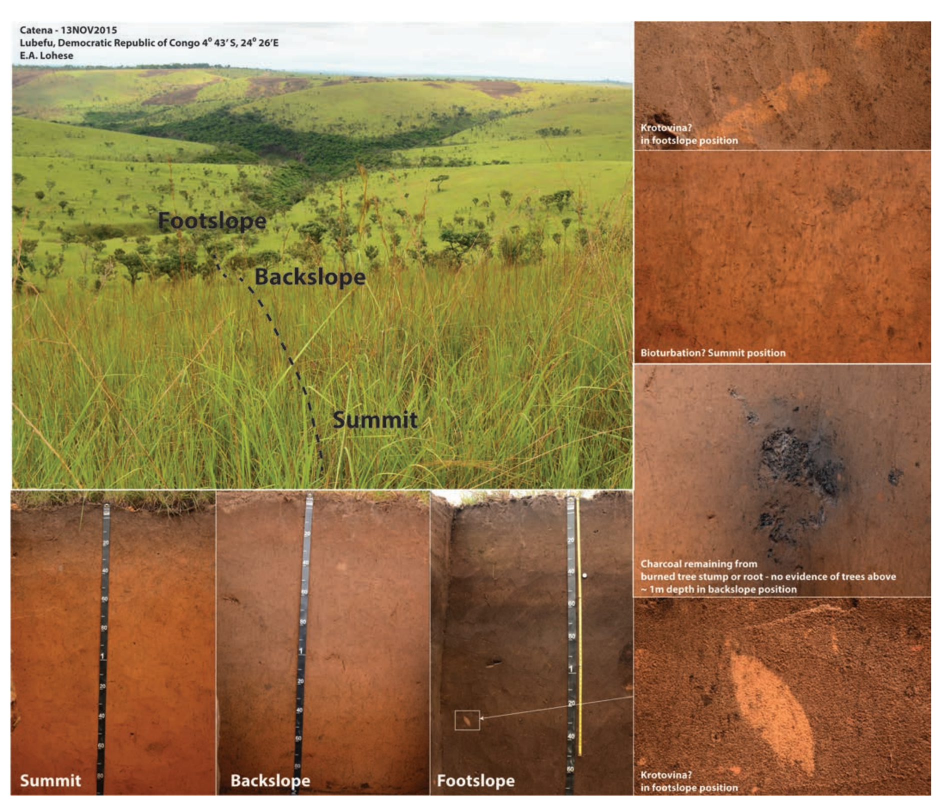

Figure 2. Combination figure showing variability in soil morphology and soil features down a catena in Tropical Savanna (Aw) near Lubefu, DRC.

Topography:

Topography exerts a central influence on soil properties within our investigated study sites, resulting in strong differences across catenas. Figure 2 shows a catena investigated in the Aw tropical savanna zone near Lubefu, DRC. The bottom left-hand panels show three soil profiles from summit to footslope. Soil morphology varied significantly down this catena. The very striking differences in soil color to much deeper depths (chromas and values < 3/3 to a depth of almost 2m) at the footslope demonstrate the strong effect of topography on soil morphology.

Carbon stocks (kg/m^2) in the top 2m increased down the catena from 6.5 kg/m^2 at the summit to 8.9 kg/m^2 on the backslope, and finally to 19.4 kg/m^2 at the footslope; 0-20cm average pH increased from 4.2 - 4.5, and 0-20cm average SOC concentrations increased from 0.58% - 0.67%. Most of the increase in carbon stocks at the footslope was therefore due not to increases in carbon content of the materials themselves, but rather the deeper distribution of carbon in the profile.

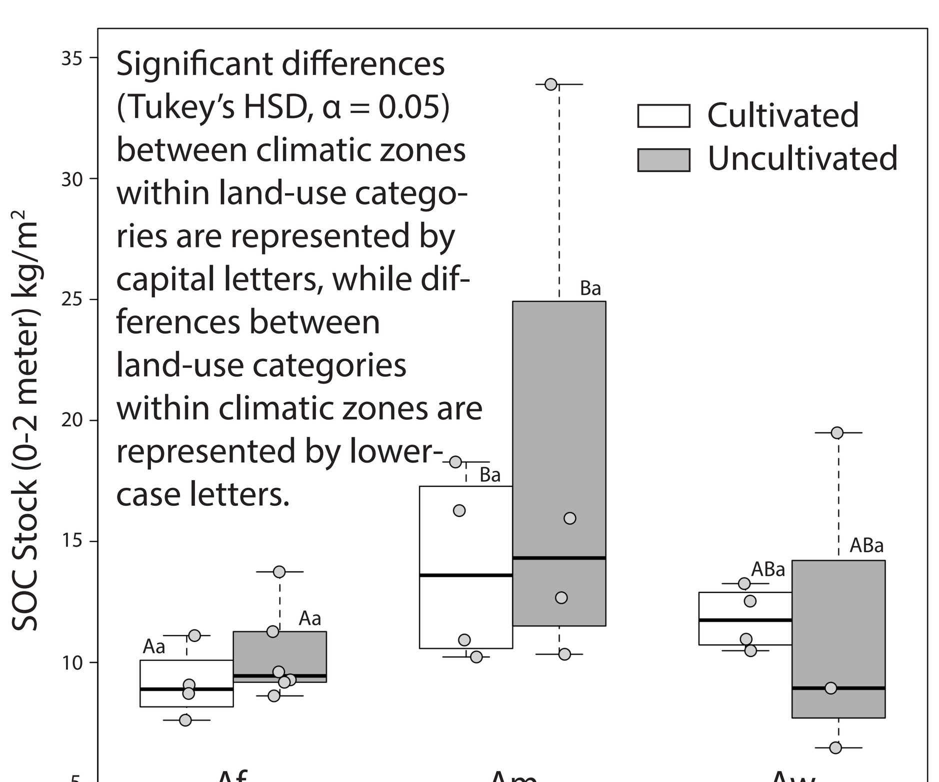

Figure 3. Boxplot and stripchart of 0-2 meter soil organic carbon (SOC) stocks for cultivated and uncultivated soils by climate zones.

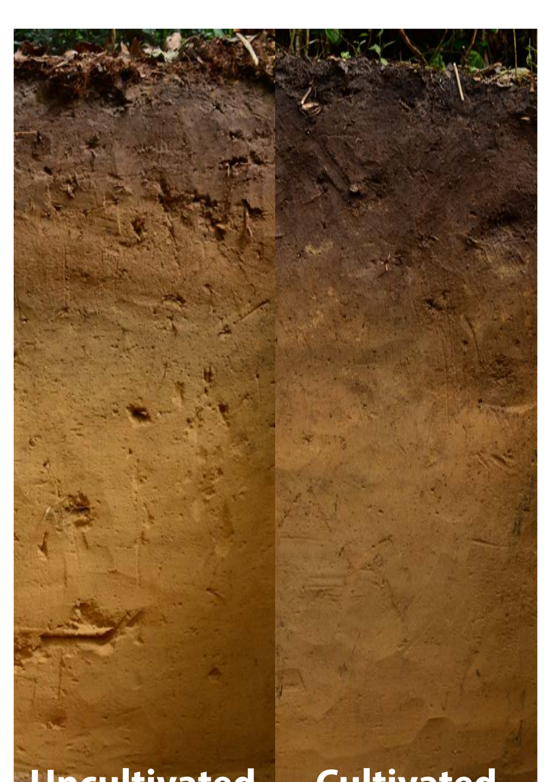

Figure 4. Adjacent Uncultivated and Cultivated profiles in forest within the Am climatic zone.

Land Use:

Investigations of paired cultivated and uncultivated sites within climatic zones revealed differences in morphology (particularly in Am and Aw), but no significant differences in 0-2m SOC stocks (Figure 3) or pH values.

Particularly in forest soils (Af and Am sites - Am pictured in Figure 4), cultivation resulted in thickening of A horizons, weakening of eluvial layer expression, and loss of the litter layer.

Figure 5. Representative landscapes and soil profiles across the climatic gradient from Tropical Rainforest (Af) - Tropical Monsoon (Am) - Tropical Savanna (Aw). Profile codes and preliminary classifications are included at the bottom of each profile picture. These classifications are based primarily on field textures and assumed relationships between pH and base saturation.

Climate:

Soil properties and morphology varied significantly across the broad climatic gradient from Tropical Rainforest to Tropical Savanna. It is important to note that vegetation co-varies along this climatic gradient. In Tropical Rainforest (Af), 80% of the investigated soils were in forest (20% in savanna); in Tropical Monsoon (Am), 50% of the investigated soils were in forest (50% in savanna); and in Tropical Savanna, 100% of the investigated soils were in savanna. Soils in Tropical Rainforest (Af) were generally charcterized by thin (6-10 cm) Oi horizons abruptly separated from the underlying mineral soil, while soils in Tropical Savanna (Aw) were characterized by well homogenized and thickened A horizons (Figure 5). Both types of generalized morphologies were present in the Tropical Monsoon (Am) climate, where vegetation was intermixed. Bioturbation was strongly evident in Tropical Savanna soils and much less evident in Tropical Forest soils (Figure 2).

Gradients in pH and SOC (%) with depth were generally steeper in Tropical Rainforest (Af) than (Aw) (Figure 6A and 6B). As a group, Am soils exhibited much greater variability in soil properties with depth than either Af or Aw soils. Topsoil pH increased from Af to Aw, while topsoil SOC concentrations decreased from Af to Aw (Figure 6D and 6E). Carbon stocks (0-2m) peaked in the Tropical Monsoon (Am) zone (Figure 6F).

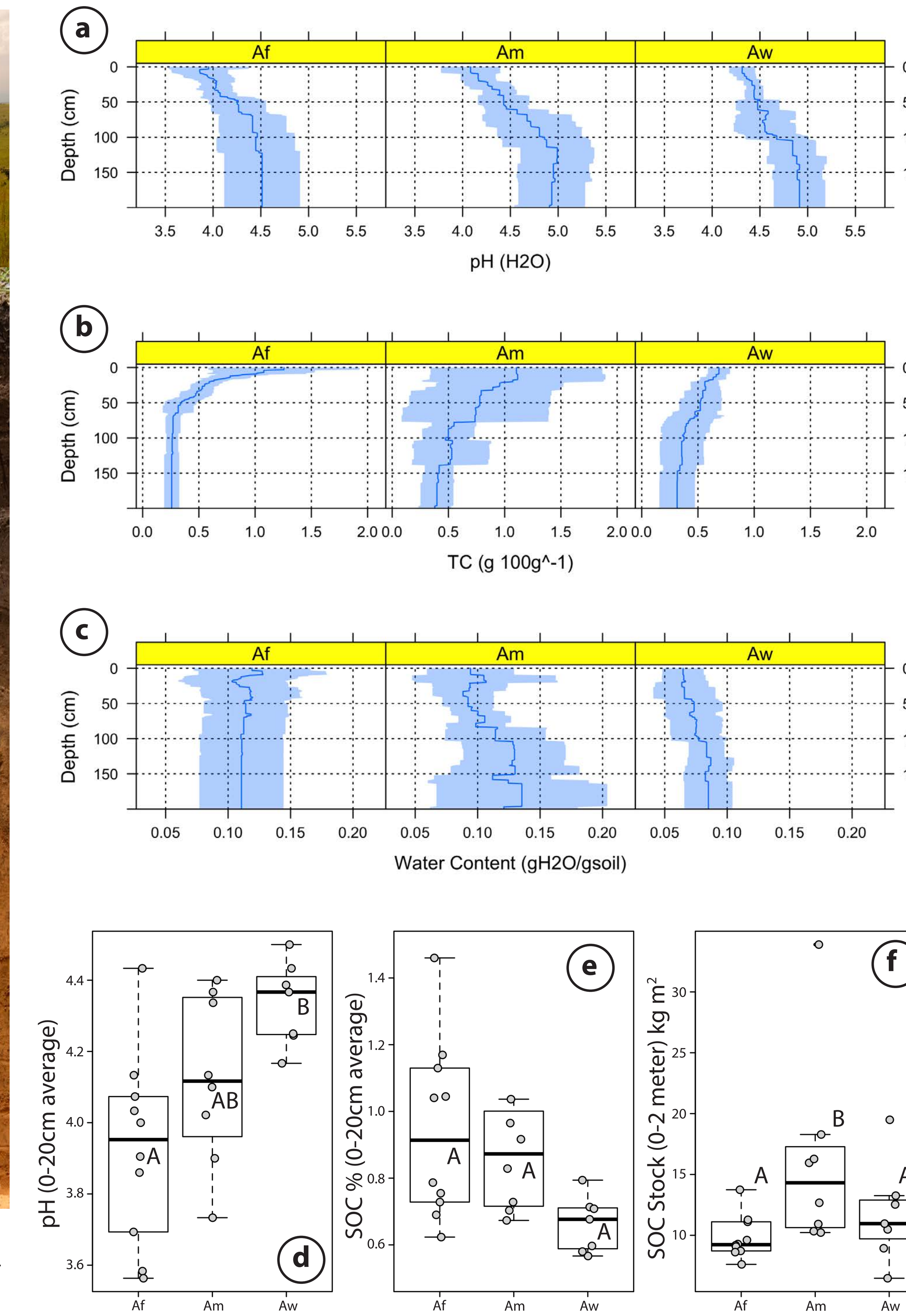

Figure 6. Plots of slabbed depth profiles (using the AQP package in R (Beaudette et al., 2013)) of **(A)** pH (H2O), **(B)** SOC, and **(C)** gravimetric water content for Af, Am and Aw climatic zones. In figures 6A, 6B and 6C, the dark blue line in each panel represents the group average of each 1-cm slab (for Af, n = 10; for Am, n = 8; and for Aw, n= 7), plotted with depth in the profile (all profiles were described to 2m), while the shaded blue region is represents +/- one standard deviation from the mean, calculated for each individual depth increment.

Boxplots and stripcharts of 0-20 cm average **(D)** pH and **(E)** soil organic carbon (SOC) for Af, Am, and Aw climatic zones. Each point in the stripchart represents the slabbed 0-20cm average for a single profile (using the AQP package in R (Beaudette et al., 2013). For all boxplots, letters show signifcicant differences between groups (Tukey's HSD at α = 0.05). **(F)** 0-2 m SOC stocks (kg/m2) across climatic zones, calculated as the sum of SOC stocks by horizon for each profile to a depth of 2m using carbon concentration, bulk density, and horizon thickness data.

Figure 7. E.A. Lohese teaching soil morphology to a group of Tshumbe University agronomy students.

Figure 8. E. A. Lohese conducting research with-students - ISEA-Mukumari, Lomela, DRC

Ongoing Work and Collaborative Efforts:

Ongoing work involves resolving additional questions about the genesis, distribution, and effects of managament on soils across the climatic gradient in central DRC in collaboration with students and faculty at Tshumbe University of Notre Dame. Work in 2017 will focus on additional data collection, information transfer, and capacity building. This foundational work will assist in the development of improved management strategies for crop production on the diverse soil types and climates of DRC.

References: IFPRI, 2015. Food Security Portal; Beaudette et al., 2013. Computers and Geosciences 52: 258-268; R Core Team, 2016. R: A language and environment for statistical computing.

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