Geomorphic thresholds

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Long-Term context: Arid and semiarid ecosystems are linked to geomorphic thresholds. Soils supply plants water and nutrient and are habitat for vertebrates, invertebrates, and billions of microorganisms (Bestelmeyer et al. 2003; 2015). Vegetation alters soil by secreting organic acids, mining mineral nutrients, breaking down rock by root expansion, and preventing erosion as ground cover while burrowing animals mix soil and microbes decompose organic matter and control oxidation-reduction reactions.

Approach: Our approach to understanding these linkages is to examine vegetative-soil-geomorphic patterns across multiple spatial and temporal scales. At the landscape scale, for example, topography affects microclimate as a result of elevation, lateral redistribution of water, and slope orientation, which affects soil water and temperature impacts vegetation. Perturbations, like overgrazing, propagate through this system as a consequence of selective herbivory and seed dispersal that reduces ground-cover and promotes erosion and sedimentation (Fig. 1, Left).

Fig 1. (Left) Conceptual framework showing linkages between ecological, soil, and geomorphic factors and processes, and their interactions with microclimate in dryland systems (Monger and Bestelmeyer 2006). (Right) A resistance index (RI) showing sensitivities of grassland to shrub invasion on Jornada landforms since 1858 (Rachal et al. 2012).

Specific objectives in the past 3 years were to continue mapping vegetative-soil-landforms patterns. These analyses have revealed that C4 grasslands on certain landscapes are more resistant to change than others when viewed in the context of 150+ years. The most resist C4 grasslands are on the heavy-textured depressions that receive run-on water from neighboring slopes (Figure 1, Right). The least resistant landforms (i.e., the most vulnerable to invasion by C3 shrublands) are on bajada landforms that lose water to runoff.

Our carbon isotope results support these conclusions. Comparison of δ13C values were made along two transects of backhoe trenches that descended a bajada into an alluvial flat (Fig. 2). These trenches made it possible to trace carbon isotopes both laterally (giving a comparison across the landform boundary) and vertically (giving a comparison through time). Laterally, the modern soils have δ13C values suggesting 32% C4 on the bajada vs. 52% C4 in the alluvial flat. The paleosols have 73% C4 on the bajada vs. 66% C4 in the alluvial flat (Fig. 5). Vertically, the bajada experienced a significant loss of C4 grasslands beginning in the mid Holocene (73% vs. 32%), in contrast to the alluvial flat where there was a decline, but not a replacement of C4 vegetation (66% vs. 52%).
Fig 2. Comparison of δ¹³C values of modern soils vs. underlying paleosols across a bajada–alluvial flat boundary (Monger et al., 2009). The wavy horizontal line in the picture and in the two graphs to the left corresponds to the depth of the buried land surface and marks the top of the paleosol.

**Relationship with the LTER VI proposal:** This objective falls under Obj. 5 (b) Patterns in soils and geomorphology.

**Future analyses:** We will continue to quantify the conceptual model linking Jornada ecosystems with geomorphic thresholds (Figure 1, Left). Soil moisture, for example, is being measured at multiple depths in 4-hour intervals at the Soil Climate Analysis Network site on the eastern bajada in neighboring grassland, dune, and bare sites. An array of other sites across the Jornada, such as the meteorological stations at the NPP sites, are also measuring soil moisture as well as soil temperature. We plan to investigate how soil climate regimes are migrating at the landscape and regional scales and how these lateral shifts will affect vegetative feedbacks to soils and geomorphic thresholds.

**Literature Cited:**


Spatial and temporal variability of plant-available water in calcium carbonate cemented soils and consequences for arid ecosystem resilience

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Long-term context: Increased variability in precipitation, including frequency of drought, is predicted for many arid and semiarid regions globally. The ability of soils to retain water can increase resilience by buffering vegetation communities against precipitation extremes. Little is known, however, about water retention by carbonate cemented soil horizons, which occur extensively in arid and semiarid ecosystems (Fig. 1). It has been speculated that they may significantly modify vertical and temporal distribution of plant-available water (PAW). Encroachment of woody shrubs into historic desert grasslands is a major problem throughout the world, and it is unclear how soil water dynamics are affected by woody encroachment in carbonate cemented soils.

Approach: To investigate carbonate cemented soil water retention and dynamics, replicated experiments at two spatial scales were conducted in a mixed shrub-grass community on the Jornada under contrasting precipitation patterns (Fig. 2): (1) a pasture scale study where PAW was monitored at three sites across soils with differing degrees of carbonate horizon development: no carbonate horizon, a horizon partially cemented with carbonates (calcic), and a horizon continuously cemented with carbonates (petrocalcic); and (2) a companion patch-interspace scale in a shallow petrocalcic soil where PAW was monitored in unvegetated interspaces and under mesquite canopies. In both studies, plots

Fig 1. Global distribution of soil inorganic carbon (SIC) within areas where calcic or petrocalcic horizons likely occur. The influence of carbonates on soil water dynamics in the top meter will increase with increasing amounts of SIC.

Fig 2. Seasonal accumulated daily precipitation as a percent of long-term average

Fig 3. PAW within calcic and petrocalcic horizon (~ 50 - 80 cm) and comparable depths in the sandy soil (a) and contrast p-values (b, c and d) comparing plant-available water in calcic, petrocalcic, and sandy soils.
were instrumented with TDR moisture probes, both above and within the carbonate cemented horizon (if present).

**Results:** In the pasture scale study, both carbonate cemented horizons absorbed and retained significantly greater amounts of PAW for several months following an extremely wet winter and summer compared to the non-carbonate soil (Fig. 2, 3). Following a wet summer, the petrocalcic horizon retained very high PAW (16 to 18% volumetric or ~72 to 80% of soil water holding capacity) through early spring of the following year, more than double the PAW retained by similar depths in the non-carbonate soil. Water dynamics during extreme events provide a mechanism to explain observations that perennial grasses exhibit greater resilience to drought when carbonate cemented horizons occur at shallow depths (< 50 cm).

In the patch-interspace study, soils under both cover types maintained large increases in available water content for several months during a wetter than normal winter and summer (increases of 0.08 to 0.16 m$^3$ m$^{-3}$) (Fig. 2, 4). Interspace soils absorbed significantly greater quantities of water during the winter and retained more water into the spring than soils under shrubs. In contrast, soils under shrubs initially absorbed greater volumes of water during and following summer rains. Results from both studies indicate that the water holding capacity of the entire profile, including horizons cemented with carbonates, should be considered when evaluating the potential resilience of vegetation communities to broad-scale drivers. Observed patterns of plant available water at the patch-interspace scale, however, do not support the hypothesis of greater resource availability under shrubs. Similar or greater water availability in shrub interspaces indicates that concentration of soil water under shrubs may not be a process limiting grass recovery on these soils.

**Relationship with the LTER VI proposal:**
This research falls under Obj. 1 Grasslands -> shrublands transitions.

**Literature Cited:**
