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Effects of Holocene vegetation change on soils across the forest-grassland transition, northern Minnesota, and implications for erosion processes

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Boundaries between forest and grassland in the midlatitudes and their shifts in response to Holocene climatic change, provide opportunities to detect effects of life on landscapes. In northern Minnesota, USA, paleoecological research has documented that grassland and/or savanna expanded eastward in the dry early to middle Holocene. In the late Holocene, forest cover expanded westward at the expense of savanna and grassland. We studied soils at 20 sites spanning the forest-grassland transition. A dramatic change in soil morphology coincides approximately, though not exactly, with that transition as recorded in 1870s-1880s land surveys, suggesting that soils change rapidly in response to forest expansion (we are attempting to constrain the timescale of response through radiocarbon dating of deep soil organic matter in which stable C isotopes record past presence of grassland). The key changes from grassland to forest are loss of organic matter below a thin surface A horizon and greatly enhanced mobility and downward translocation of clay—particularly smectite—in forest soils. This results in upper soil horizons that have relatively low smectite content and low microaggregate stability (as detected through laser diffraction analysis of aggregate disintegration in laboratory experiments), especially below the thin A horizon. The best explanation for this change appears to involve differences in how OM is added to and accumulated in the soil under forest and grassland; soil acidity and base saturation change more gradually eastward along a gradient more likely to reflect climate than vegetation. Evidence of bioturbation (especially gopher burrowing) is much more common at former grassland sites. In addition to mixing OM downward in the soil, burrowing moves detrital carbonates upward, probably enhancing OM accumulation and aggregate stability.

Research on geomorphic response to Holocene climatic change in the Midwestern US has often emphasized higher potential sediment yield from grasslands that expanded under dry conditions, as compared to forests where runoff is rare. Our research highlights soil changes that may act in the opposite direction—in the late Holocene, at least, grassland soils have highly stable aggregates that could limit seal formation, runoff, and slopewash erosion. At the same time, the eastward retreat of forest during the early-middle Holocene could have initially left soils vulnerable to higher erosion rates, especially after fires and in rugged moraine topography with steep slopes. Holocene alluvium or lake sediment may preserve a record of the kinds of soils supplying sediment and how they changed over time, allowing a test of these hypotheses. Sediment eroded from fully developed grassland soils is likely to have a different signature (higher OM and smectite, different organic C isotope ratios) than that from the forest soils. The soil contrasts across the forest-grassland boundary are also likely to affect future geomorphic response to anthropogenic climate and land use change in this region. Historically, row-crop agriculture has largely been confined to the grassland soils, where resulting erosion may be moderated by strong structure; however, a warmer climate in coming decades could promote its expansion onto presently forest-covered soils with much weaker structure.