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Parent material influence on soil response to vegetation change, Southeastern Minnesota, U.S.A.

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ABSTRACT

Soil morphology changes dramatically across the former transition from forest to grassland in the Midwestern U.S.A. That vegetation boundary shifted as a result of Holocene climatic change and fire suppression following Euroamerican settlement, but the timescale of soil response to those vegetation changes and the factors that influence it are poorly known. On steep colluvial slopes of southeastern Minnesota, Mollisols with thick, dark A horizons typically associated with grassland are found today under deciduous forest. Soils with much thinner and/or lighter-colored A horizons occur immediately up- and downslope of the forest-covered Mollisols. Most of the soils with thick A horizons are not in topographic settings found to favor organic matter accumulation in other landscapes. Principal component analysis highlights important axes of textural and mineralogical variation among horizons of these soils, often related to parent material properties. Soils with and without thick A horizons are separated along one principal component heavily loaded by high pH, reflecting the presence of dolomite fragments in the hillslope sediment that soils with thick, dark A horizons formed in. Stable C isotope analysis reveals that the Mollisols with thick, dark A horizons under forest had C input from vegetation with abundant C_4 grasses in the past. Public land survey data also indicate replacement of grassland or savanna by forest since 1854 on colluvial slopes where forest-covered Mollisols occur today. We propose that the soils with thick, dark A horizons under forest today reflect a lagged response to vegetation change, from grassland or savanna to closed forest. Their thick A horizons and some C_4-derived organic matter may be preserved because dolomite weathering releases abundant Ca^{++} and Mg^{++} that favor aggregation and organic matter stabilization. Soils with thin A horizons just up- or downslope may also have formed partly under grasses, but have responded more quickly and/or more substantially to vegetation change.

1. Introduction

Major changes in soil morphology associated with the midlatitude forest to grassland transition were recognized early in the history of pedology, most notably in the work of Dokuchaev (1883). There is also a history of hypotheses on relict soil characteristics related to geologically recent shifts in the location of the forest–grassland boundary (Bronger, 1991; Miedema et al., 1999; Neustruev, 1927). In the Midwestern USA prior to the nineteenth century expansion of agriculture, there was a generally westward transition from deciduous forest to tallgrass prairie, with an intermediate zone of savanna or open woodlands (Fig. 1a). The complex spatial pattern of this vegetation boundary was recorded in detail by nineteenth century public land surveys and has been attributed to effects of both climate and wildfire, with discussion of the relative role of each factor continuing up to the present (Curtis, 1959; Grimm, 1984; Nelson and Hu, 2008; Shuman et al., 2009). Across this forest–prairie ecotone, there is a corresponding transition from Alfisols to Mollisols (generally from Luvisols to Chernozems or Phaeozems in the WRB classification). Studies in Minnesota, Iowa, and Illinois have documented marked changes in soil morphology over a distance of a few tens of kilometers or less, with thinner A horizons and more distinct textural contrasts between A or E and B horizons on the forest side of the boundary (Bailey et al., 1964; Mason and Nater, 1994; Severson and Arneman, 1973; White and Riecken, 1955).

The fact that these morphological changes occur at, or close to, the nineteenth century vegetation boundary is especially noteworthy because paleoecological research has demonstrated that the forest–prairie boundary has shifted substantially over the past 10,000 yr (Webb et al., 1983; Williams et al., 2009). In fact, even where forest expanded into prairie within the last millennium, Alfisols sometimes dominate the landscape recently occupied by forest (Grimm, 1983; Umbanhowar,

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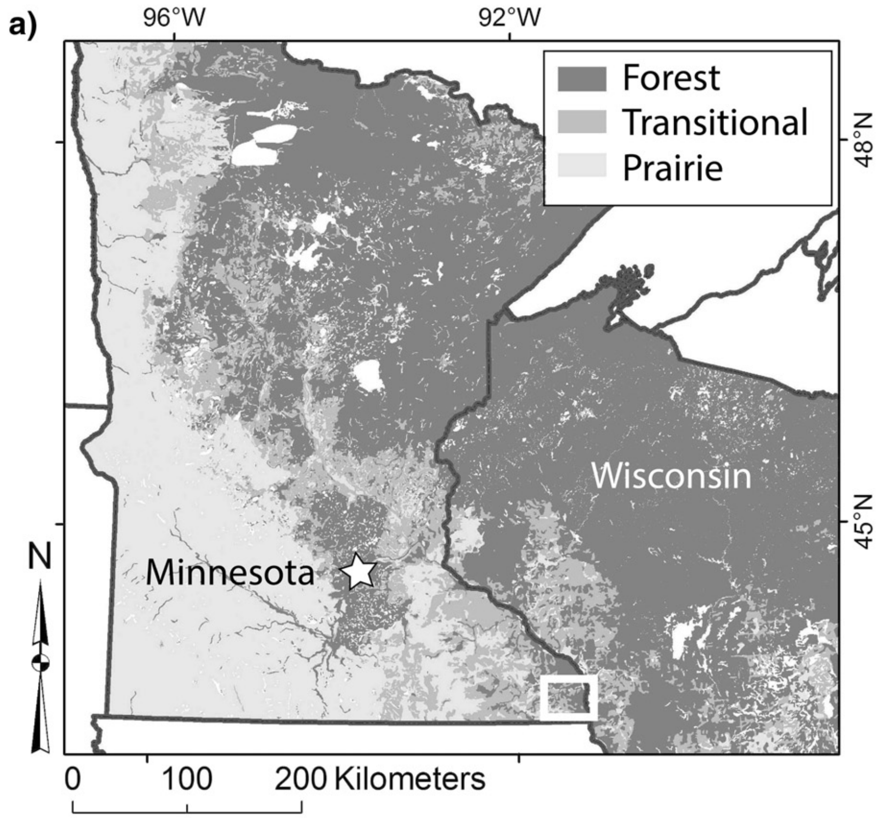

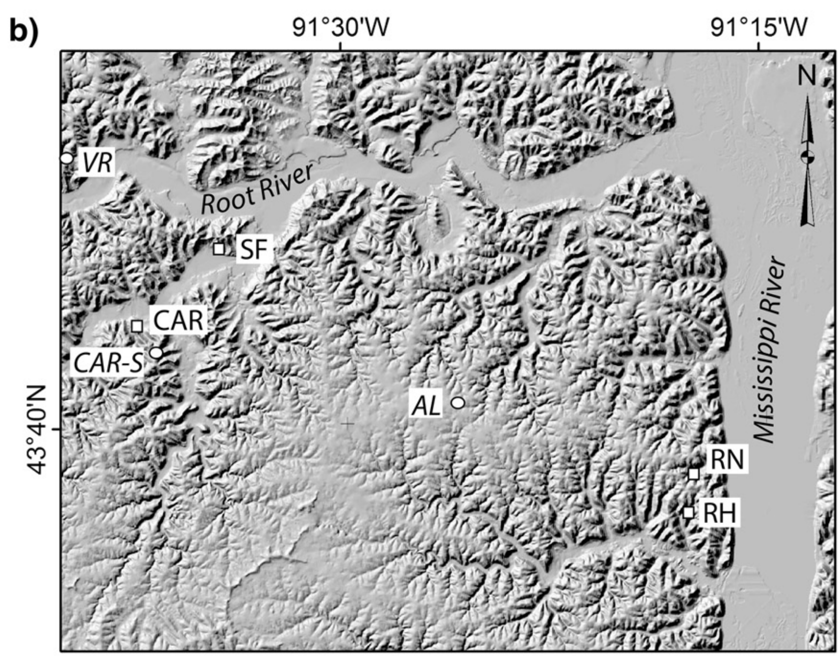

Fig. 1. a. Vegetation of Minnesota and Wisconsin at the time of 19th century public land surveys (Marschner, 1974; Finley, 1976). White box is study area, star marks area where forest expansion in past 1000 yr is documented. b. Topography of the study area (based on US Geological Survey 30-m DEM) with study site locations. Sites in italics are individual ridgetop profiles in thick loess, at other sites, multiple soils were sampled on hillslopes.

2004). Thus, it appears that under the right circumstances, soil morphology can change rapidly in response to the transition from prairie to forest.

On the other hand, some Mollisols near the forest–prairie boundary in Minnesota are forest-covered today, or were at the time of nineteenth-century land surveys (Almendinger, 1990; Buell and Cantlon, 1951; Grimm, 1983). One obvious explanation for these anomalous soils is that they have not had enough time to respond to recent advance of forest into prairie (e.g. Geis et al., 1970). This raises the question of whether response time to vegetation change could be longer for soils in certain