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Digital soil mapping of a red clay subsoil covered by loess

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ABSTRACT

A red clay subsoil is commonly found in the soils of the Driftless Area of Wisconsin, USA. The red clay is buried by a layer of loess and occurs on uplands underlain by dolostone. It is assumed to have derived from the impurities of the weathered dolostone. The red clay has implications for groundwater recharge and lateral flow of water through the landscape as well as the fixation of excess phosphorus from animal manure and inorganic fertilizers. Here we have produced digital soil maps at different levels of probability of the red clay presence, the depth to the red clay, and its thickness. Five hundred and sixty-one soil observations were made in a 7000 ha study area and were used to investigate the relationship of the red clay to landscape characteristics and short range soil variability. Soil observations and environmental data were used to create digital soil maps using regression models and kriging. Compared to the described soil series for the study area it was found that the red clay is less red, about 10 cm thinner and contains 15% less clay. At 60% probability, the model predicts 2600 ha with red clay compared to 3300 ha from the Soil Survey Geographic database (SSURGO), 2000 ha with a 30 to 55 cm loess cover (vs. 1600 ha from SSURGO) and 1700 ha with greater 15 cm red clay thickness (vs. 3300 ha from SSURGO). It is concluded that SSURGO overestimates the total area with red clay and the thickness of the clay. This study also showed how a clay subsoil can be mapped at different levels of probability.

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1. Introduction

Digital soil mapping techniques have been used to map soil horizons and its soil properties (McBratney et al., 2003). One of the earlier studies was by Moore et al. (1993), who used terrain attributes to map the A horizon depth on hillslopes. King et al. (1999) used logistic regression and a set of covariates to map the presence of a clay loam horizon. Vanwalleghem et al. (2010) studied the relationship of topography and the depths of soil horizons using multiple regression. They found poor correlation between terrain attributes derived from a DEM and the soil horizon depths. Gastaldi et al. (2012) mapped the presence and the thickness of horizons using both logistic regression and linear regression in order to map entire soil profiles. The approach allows for the mapping of the presence of a horizon and its properties. This paper builds on these ideas and methods, and applies them to map a red clay subsoil in Wisconsin, USA.

The Driftless Area of Wisconsin is a region of stream-dissected uplands in the southwest part of the state with a size of about 41,000 km^2 (USGS, 2013). It has not been glaciated within the Quaternary period (Knox, 1982). The Driftless Area extends into the states of Minnesota, Iowa, and Illinois, but the greatest extent is in Wisconsin. Loess covers much of the landscape with the greatest depths in the western part of the state closest to the Mississippi River.

The Driftless Area was affected by a periglacial climate and associated erosional processes during the last ice age that ended about 12,000 years ago. The periglacial conditions caused some mass wasting and hillslope erosion due to solifluction (Mason and Knox, 1997). These processes reduced the thickness of loess on side slopes and resulted in accumulation in the lower parts of the landscape. Much of the colluvial material was removed after the glaciers receded (about 10,000 years ago) by alluvial activity (Knox, 1989).

A red subsoil clay occurs on the uplands in the Driftless Area of southwest Wisconsin (Knox et al., 1990). The red clay ranges from several centimeters to a maximum of several meters thick. It is present on uplands underlain by dolostone ($CaMg(CO_3)_2$) and is not documented to occur over sandstone. The red clay is buried by loess and it is sometimes described as a geologic unit named the *Rountree* Formation (Knox et al., 1990). The material has many characteristics of *Terra Rossa*, soils formed in a Mediterranean climate in the residuum of hard carbonate bedrock with additions of other materials (Merino and Banerjee, 2008). The red clay in the Driftless region contains weathering products from the dolostone bedrock and from the loess (Stiles and Stensvold, 2008).

The high clay content (35–75%) impacts the rate of groundwater recharge and the high iron content of the red clay makes it a potential sink for phosphorus (Frolking, 1978). More information is needed regarding

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the presence and absence of the red clay, its thickness, and the thickness of the overlying loess. The red clay has been mapped in county soil surveys but these polygon maps do not represent the complex nature of soils on the landscape and provide no uncertainty information regarding the properties of soils.

The objectives of this study were (i) to apply digital soil mapping techniques to obtain spatial information of the red clay, and (ii) to predict the presence and thickness of the red clay for different levels of probability. In particular, we tested the use of regression kriging with 561 data points to obtain estimates of the area with red clay and its depth. The study took place in a 7000 ha study in Wisconsin, USA. It built on a study carried out between 2004 and 2007 that used random sampling of 417 data points in the area for mapping soil classes (Zhu et al., 2009). This study makes use of those points, and an additional 144 pedons collected along catenas.

2. Materials and methods

2.1. Study area

The study was conducted near Verona in Dane County, south central Wisconsin (Fig. 1). The area is 7000 ha. Most of the land use in the study area is agriculture, with maize and soya the most common cash crops and alfalfa grown for forage, but there are also extensive areas with forest and some restored prairie (Fig. 2). Mean annual precipitation is 850 mm with a mean annual temperature of 7.3 °C.

The bedrock underlying the Driftless Area consists of nearly horizontal beds of sedimentary rocks, primarily sandstone and dolostone, with some shale. The dolostone generally forms the ridges with the less resistant sandstone and shale occurring on the slopes and underneath the valley fill (Slater and McSweeney, 1992). The insoluble content is 8.5%

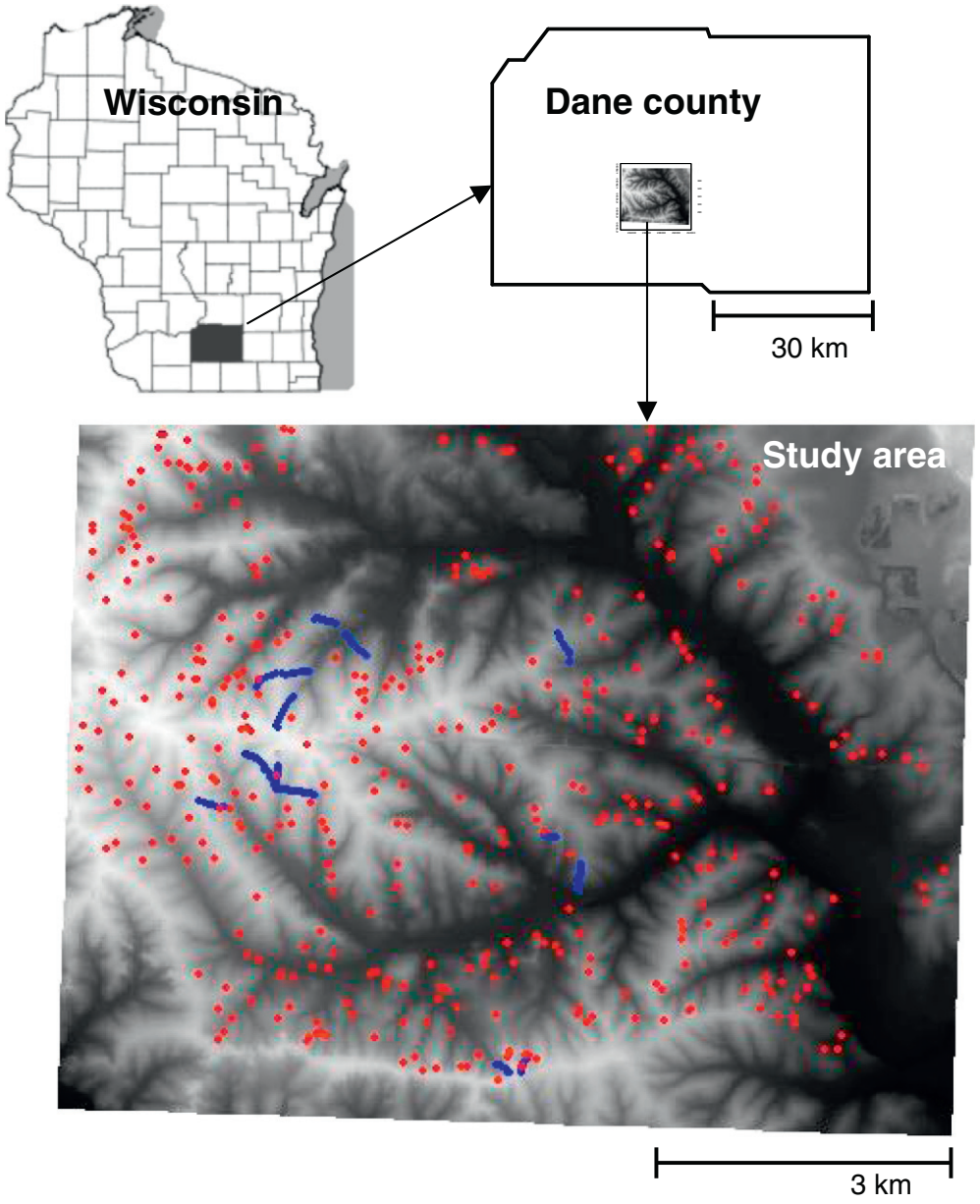

Fig. 1. Location of study area (7000 ha) in Dane County, Wisconsin, USA. Red dots are the pedon observations made in 2004–2006 ($n = 417$), blue dots indicate the pedon observations by catena sampling of 2012 ($n = 144$).