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Property values as affected by loess thickness and texture

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ABSTRACT

We tested the longstanding (but untested) premise that loess cover (thickness and texture) positively impact the value of land parcels. To do this, we visited 1178 upland sites across 12 counties in Wisconsin with a mix of land uses; each site was underlain by loess of varying thickness. We sampled the loess at each site with a 195-cm long hand auger, and measured its thickness. The per-acre value of each parcel was then determined, where possible, using an online website. Parcels that contained buildings and structures, those whose per-acre values were not listed on the web site, and sites for which we lacked accurate thickness data (because the loess was > 195 cm thick) were eliminated from the dataset, resulting in a final count of 461 sites for analysis. The data, compared statistically using simple linear and logarithmic regressions, indicate that land values are highest on sites with thicker and siltier loess. This conclusion is in agreement with observations made on the ground while sampling. The strongest correlation ($R^2 = 0.268$; P-value <0.001) with land value occurred on a composite variable, developed to mimic the total mass of fine and medium silt in a 1 cm^2 column of loess from the soil surface to the bottom of the loess, indicating that the most prized land in the study area occurs on sites with the thickest and the most “fine-silty” loess.

1. Introduction

Loess is generally defined as wind-deposited silt, irrespective of thickness. That said, many of the world’s loess deposits are many tens of meters thick. Recent research has, however, been increasingly focused on much thinner loess deposits, often less than a meter thick (Greene et al., 2009; Gild et al., 2017; Makeev et al., 2017; Waroszewski et al., 2019). Although typically dominated by silt, loess deposits can often be sandy as well (Schaetzl and Attig, 2013; Lehmkuhl et al., 2014; Obreht et al., 2015; Purtil et al., 2019).

Loess is a widespread soil parent material across much of the world (Frechen et al., 2003; Haase et al., 2007; Muhs, 2007; Schaetzl et al., 2018a; Schaetzl et al., 2018b; Zhu et al., 2018; Lehmkuhl et al, 2020). One can consider sites with loess to be “loess ground” (http://loessground.blogspot.com/). In the United States, loess is particularly widespread across the upper Midwest, the lower Mississippi River valley, and in parts of the Pacific Northwest and Alaska (Bettis et al., 2003; Busacca et al., 2003). Soils formed in loess parent materials typically have silty and/or loamy textures, both of which are excellent for the growth of most crops, because silt-dominated textures have some of the highest ranges of available water capacity of any soil texture class (Brady, 1974; USDA-NRCS, 1998; 2005). Additionally, silty parent materials provide few obstacles to building construction, except perhaps where high water tables are present. Thus, silty soils, most of which worldwide have formed in loess, have historically been of high value for a variety of land and agricultural uses. It then follows that silty soils that lack a high water table, i.e., those on uplands, would be particularly valuable.

For well over a century, agricultural productivity has been assumed to be highest on loess ground, other things being equal. Free (1911, 128) perhaps summarized it best by stating that, “Soils derived from loessial deposits are everywhere among the most fertile in the world.” This tenet had been previously affirmed by von Hauer (1875), who argued that, in Austria, exceptional fertility could be used as an indication that the soils were of loessial origin (see also Pumpelly, 1879). The exceptional “overall” quality of loess and loess ground was perhaps best explained by Keyes (1898, 302), who stated that, “Loess districts appear to be areas of exceptional fertility. Plant life flourishes luxuriantly even when in adjoining tracts not covered by the deposit only a scant vegetation is supported. The peculiar porosity of the loess gathers in the maximum amount of water, holds it, and gives it out again gradually, during the dry season.”

Because productivity/fertility are the main factors in determining

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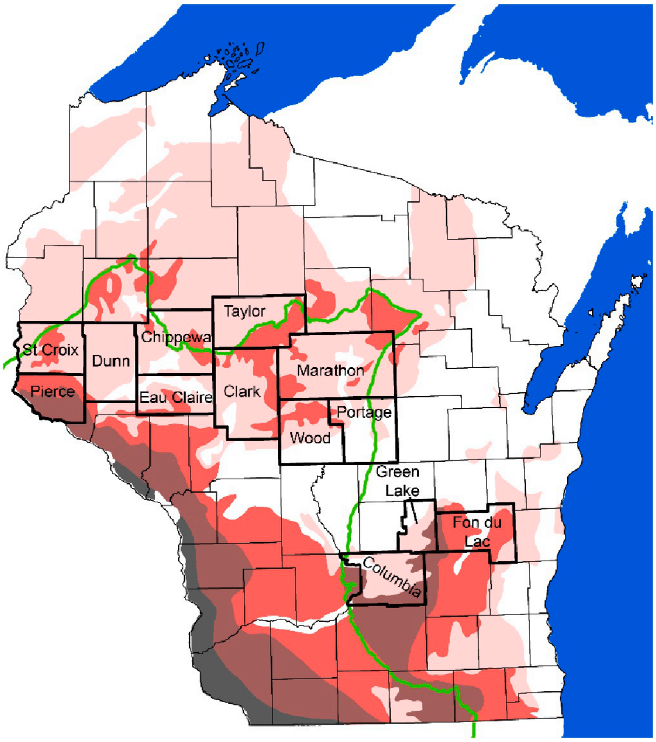

Fig. 1. Map of Wisconsin showing four broad categories of loess thickness, based on Hole (1950). Counties included in this study are outlined in bold and labelled. In both this figure and in Figure 2, the green line indicates the southern boundary of the last glacial advance. Sites south and west of this line were not glaciated during the Wisconsin advance of ca. 24,000 years ago.

the value of land in agriculture, land appraisers have, over time, developed economic assessments of land values based mainly on crop yields, as adjusted for the presence or potential for irrigation (Agamerica Lending, 2016). Thus, one might assume that a positive relationship exists between loess ground and high agricultural land values. Nonetheless, evaluation and quantification of this tenet has not, to our knowledge, been objectively performed. Thus, the purpose of our study was to evaluate the effects of loess, where it is present, on land valuation - regardless of current or future land use. To this end, we examined not only loess thickness but also several key textural parameters, to determine which types of loess "landscapes" and sites have the highest value. As data on loess distributions and thicknesses are produced in increasing detail by geologic and soil mappers, data from our study may help land managers and real estate firms estimate the potential value of loess-covered landscapes, in addition to informing future land use research.

2. Study area and methods

Our goal in this study was to objectively compare land values across a variety of upland settings or landscapes where loess is present. We chose not to compare land values on sites with vs those without loess, because sites that lack loess vary dramatically in texture and wetness. Sandy sites are generally of low value vs loamy sites are more prized. Similar conclusions could be drawn for wet sites. Thus, we restricted our analysis to *upland* sites that *have* a loess cover, and used the thickness and texture of the loess as the independent variable in our statistical analyses. We argue that the land values for such sites will be mainly influenced by the character of the loess itself.

We chose parts of Wisconsin, in the upper Midwest, USA, as a suitable area for this type of analysis, because it is variously covered with loess (Hole, 1950). Across Wisconsin, loess thicknesses range from > 7 m to areas where the loess cover is absent or scarcely detectable (Allan and Hole, 1968; Jacobs et al., 2011, 2012; Scull and Schaetzl, 2011; Schaetzl and Attig, 2013; Mason et al., 2019). Land uses are also quite variable across the state, ranging from agriculture of a wide variety of intensities, to urban areas, all set within a matrix of forest remnants in various states of management. Thus, the state is an excellent location to examine the effects of loess thickness and texture on land valuation.

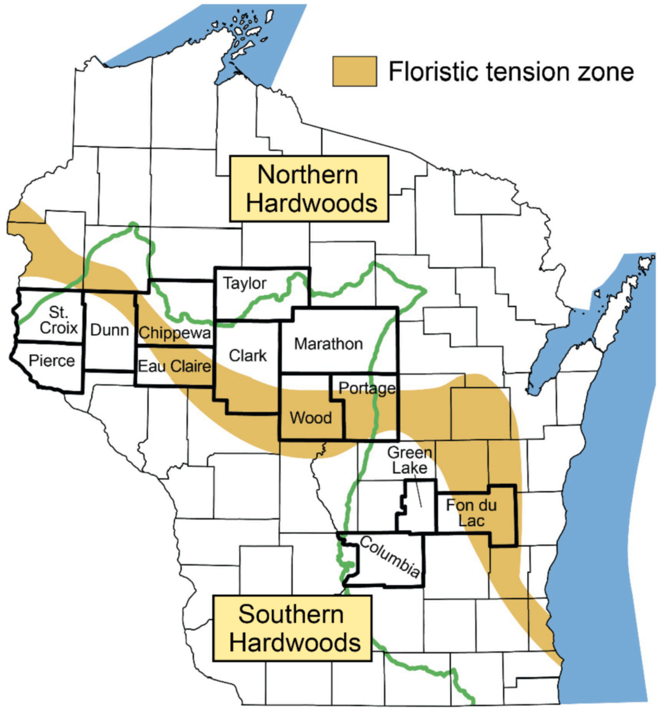

Fig. 2. Map of the floristic tension zone in Wisconsin, with the counties in our study indicated by bold outlines. After Curtis (1959).

2.1. Soil sampling and analysis

We examined land values within 12 counties in the state of Wisconsin (Fig. 1). These counties represent a wide variety of landscapes and land uses (Vale, 1997), with loess thicknesses that vary from well in excess of 5 m, near the Mississippi River, to areas where loess is thin or absent. In order to include the broadest possible representation of land uses, we also opted to use a mix of counties that were glaciated during the Wisconsin glacial advance of ca. 18,000 years ago, as well as counties that lies outside of the glacial margin (Fig. 1; Attig et al., 2011; Syverson and Colgan, 2011). Four of the 12 counties lie fully south of the floristic tension zone, as defined by Curtis (1959). This zone separates the two main floristic provinces of the state. Two other counties are fully north of the tension zone, and six straddle it (Fig. 2). Counties in the far south and west are dominated by row crop agriculture, whereas the more center-northerly counties are more invested in dairy farming, grazing and raising of livestock, and/or mixed farming practices, and generally have more land in forest. None of the counties are within the economic "watershed" of any of the state's eight largest metropolitan areas, which we feared might have overly influenced land values. Of the cities within our 12 county study area are Eau Claire, the 9th largest city in the state, with only ≈65,000 people. The next largest city within the 12 county study area is Fon du Lac, with a population of only ≈43,000.

Using Hole's (1950) map (Fig. 1) as a starting point, we refined the distribution of loess presence/absence and thickness in our study area by using county soil maps produced by the Natural Resources Conservation Service (NRCS). Data from these maps, in digital forms, were downloaded from the NRCS's Soil Data Mart web site (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/wi/soils/?cid=nrcseprd1326315) and

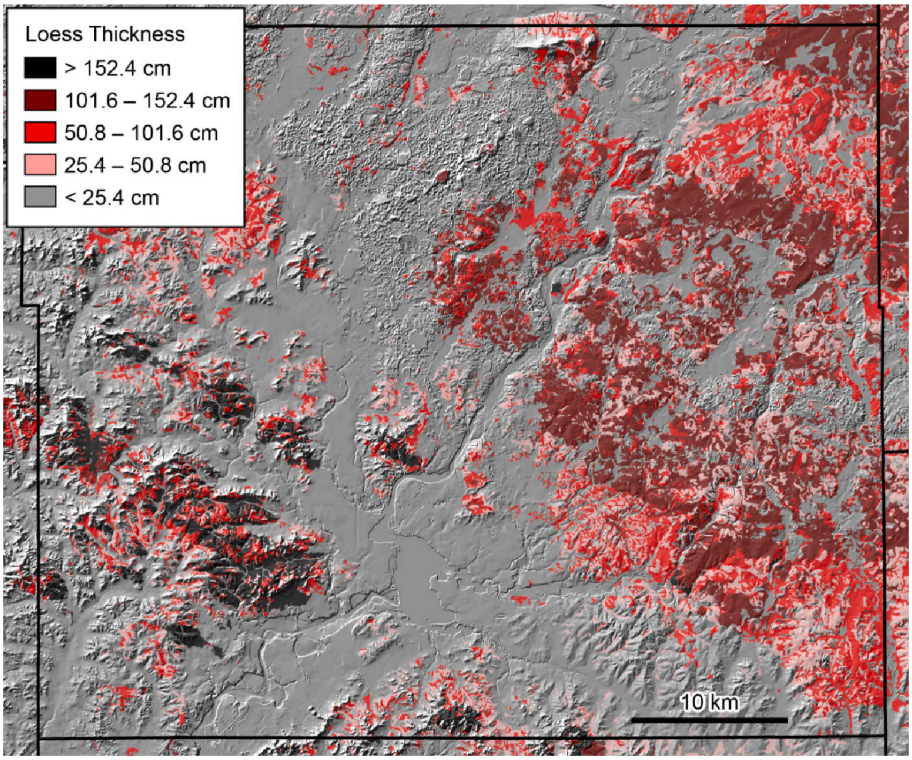

Fig. 3. Map of Chippewa County, Wisconsin, showing the distribution and thickness of loess, as derived from the county soil map (Jakel and Dahl, 1989), on a hillshade base derived from a 10-meter digital elevation model. Note the variability in loess coverage and thicknesses across the county.

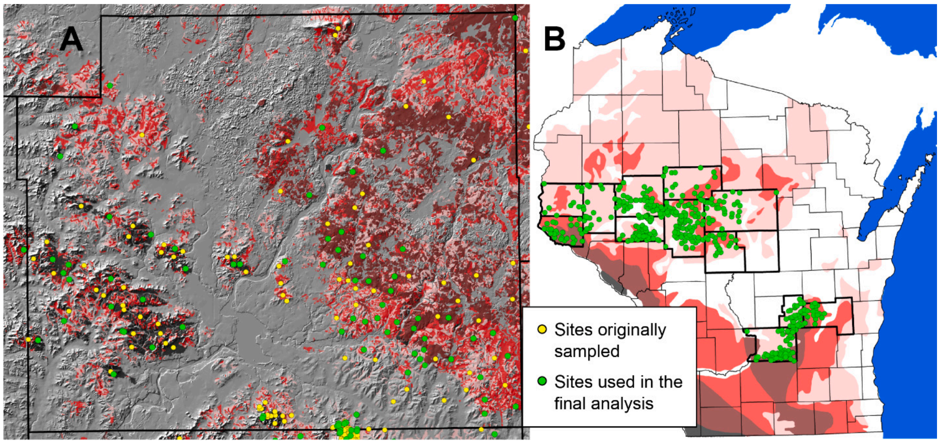

Fig. 4. The distribution of samples (A) across Chippewa County (with a similar background and color legend to that shown in Fig. 3) and (B) across the 12-county study area.

imported into a GIS. Using soil series descriptions available online (https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053587), we next determined the parent material(s) for most of the soil series in the study area. When the parent material description for a soil series was listed as loess, we entered these data and the loess thickness indicated in the official soil series description into the GIS attribute table, and coded the map unit symbology in the GIS coverage accordingly (Fig. 3). The GIS data were then loaded onto a laptop computer equipped with a built-in GPS unit, so as to facilitate navigation to predetermined sites for sampling.

Our sampling goal was to obtain a large number of loess samples from broad upland sites, using a repeatable methodology. Upland sites are not only the most geomorphically stable areas in the landscape, but typically also have few limiting factors related to high water tables and wetness, which could affect their land values. Placing the soils data (semi-transparent) on top of a hillshaded digital elevation model (DEM) in the GIS helped identify these kinds of potential sample sites. Geographically, we sought to sample uniformly across uplands, aiming for a final sample density of at least one sample every 20–30 km^2, with slightly higher densities in areas where the loess deposits are more prevalent, or where loess thicknesses change rapidly across short distances.

Samples of loess (500–600 g) were obtained, and loess thickness determined, at 1178 sites, using a 195-cm long hand auger (Fig. 4). For details on this sampling method, see Schaetzl and Attig (2013) or Schaetzl et al. (2021). Loess thicknesses reported here should be viewed as maximum thicknesses; at upland sites, loess should have been optimally preserved and minimally eroded, whereas on sideslopes much of

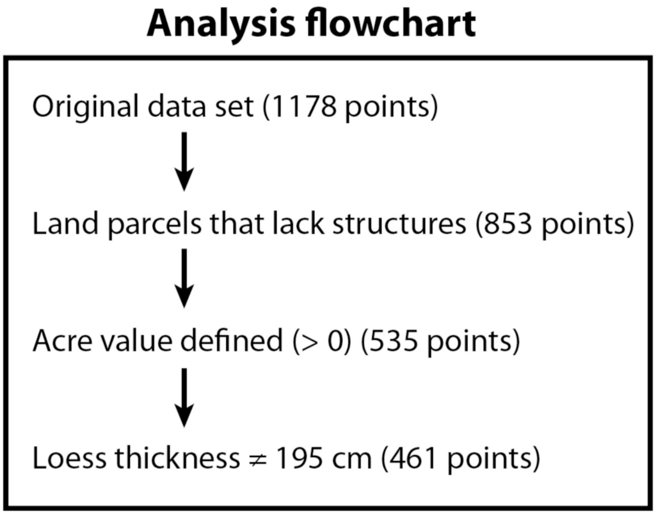

Fig. 5. Flowchart of data analysis and refinement.

the loess could potentially have been eroded. Our goal was to obtain an amalgamated sample of loess from auger shavings that was representative of the entire loess column/deposit, while avoiding loess near the underlying lithologic contact, which sometimes is sandier and/or mixed with the underlying sediment (Schaetzl and Luehmann, 2013; Luehmann et al., 2016).

All samples were air dried, lightly ground to pass a 2-mm sieve, and passed through a sample splitter and recombined (3–4 passes total), in order to achieve the high level of homogeneity necessary for analysis on a Malvern Mastersizer 2000E laser particle size analyzer. We did not remove carbonates or organic matter from the samples, as the loess is not calcareous, and because most samples were very low in organic matter. From each homogenized sample, 2-g subsamples were removed and dispersed in a water-based solution of $(NaPO_3)_{13}\cdot Na_2O$, after shaking for 20 mins. As discussed in Miller and Schaetzl (2012), the small subsamples used in laser particle size analyzers are sometimes not representative of the larger sample. Thus, in order to maximize the representativeness and precision of the particle size data, we analyzed two subsamples from each larger loess sample and compared the data. When the suite of particle size data were statistically "similar," we used the mean values for all subsequent analyses. But when the data from the two runs were less similar (see Miller and Schaetzl (2012) for details), a third, or sometimes even a fourth subsample was run. In these situations, the two most comparable samples were used to generate the mean particle size values used in subsequent analyses. A variety of textural parameters were output for each of the loess samples and compiled in a database for subsequent comparisons with land values of the parcels on which they exist.

2.2. Land values

Because most of Wisconsin has been settled and farmed for well over 150 years, we assumed that current land values, as reflected in assessments, have had time to adjust to the many physical variables that exist on the landscape. In other words, low-quality parcels that may have been unwittingly purchased many years ago for too-high a price have by now had ample time to drop in value, and vice-versa. Thus, we argue that contemporary data on land values are reflective of what the land would currently sell for on the open market.

Loess data were compared to land values by examining data on land value/per acre for parcels that contained a loess sample. Land values were determined from acrevalue.com. AcreValue analyzes data on soils, climate, crop rotations, taxes, interest rates, and corn prices to estimate the value of an individual field or plot. The web site compiles public data sources ranging from deed records of land transactions, classifications of crop rotations and soil properties, and climate data from > 15 local, state, and federal government agencies, private entities, foundations, and universities, to arrive at values for land parcels. Parcel boundaries are obtained from county assessor records. Additional details of the algorithms used to generate the value of a given parcel are not provided on this acrevalue web site.

PLSS (Public Land Survey System) Wisconsin section shapefiles obtained from the USDA Geospatial Clearinghouse as GIS shapefiles were used in support of the interactive process of locating each sample point; after determining the PLSS section in which a sample point was located, it was then cross-referenced in the acrevalue.com database. Only parcels with land uses such as agriculture, forest, or open land were included in the data set. We were unable to use 318 parcels whose values were undefined in acrevalue.com. Parcels with structures such as barns or outbuildings (325) were then eliminated from the remaining data set, as the value of the structure(s) would have affected the overall parcel value (Fig. 5). Lastly, we eliminated 74 sites where the loess thickness could not be determined in the field with the 195-cm long auger. We did, however, use loess thickness data from six sites that had loess thicknesses >195 cm, because here we had used a mechanical coring device to accurately measure loess thickness. We eliminated the 74 sites because loess at these locations could have ranged from 200 to as much

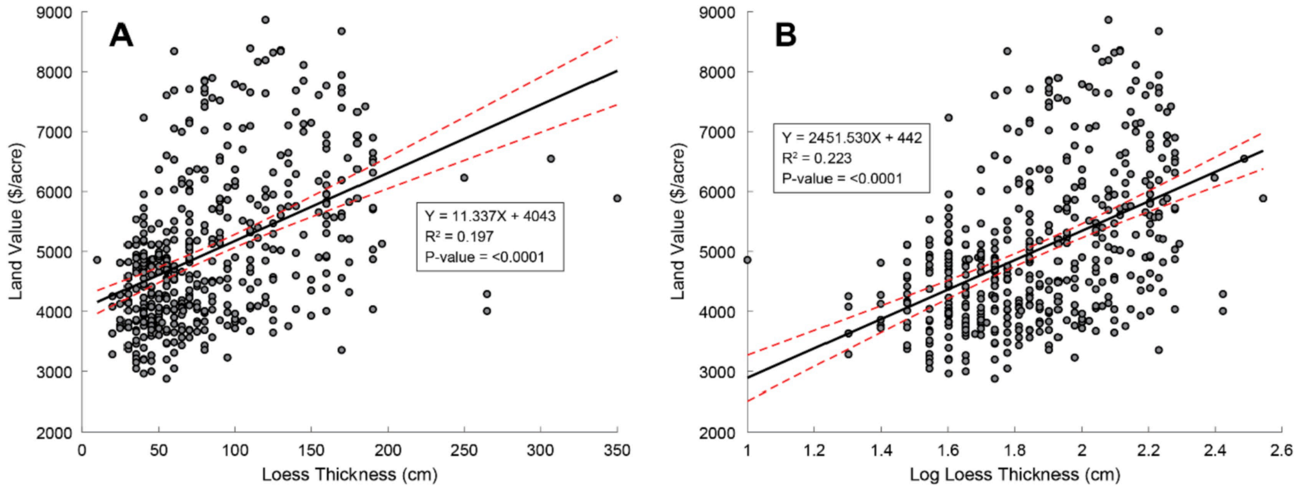

Fig. 6. Scatterplots of land value vs loess thickness using (A) untransformed data, and (B) logarithmically transformed thickness data. In this and all successive scatterplots, a 95% confidence interval window is shown.

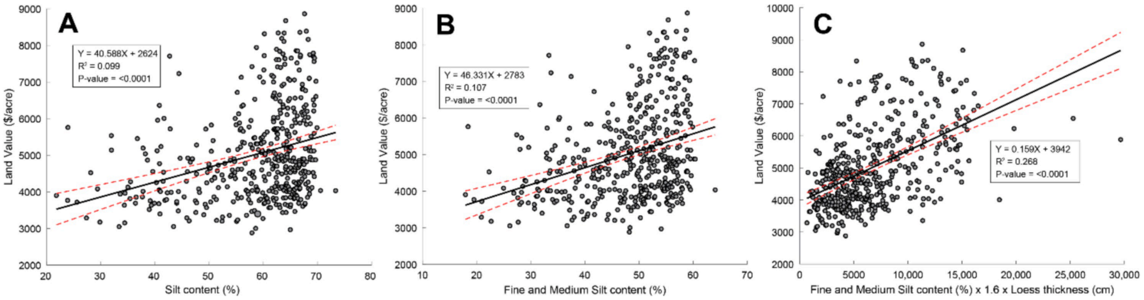

Fig. 7. Scatterplots of land value vs loess texture. A. Silt (8-50μ dia.) content. B. Fine and medium silt (8-35μ dia.) content. C. Fine and medium silt content, multiplied by loess thickness and adjusted for typical bulk density values of loess (1.6 g m^{-3}). This product is essentially the mass of fine and medium silt in a 1 cm^2 column of loess.

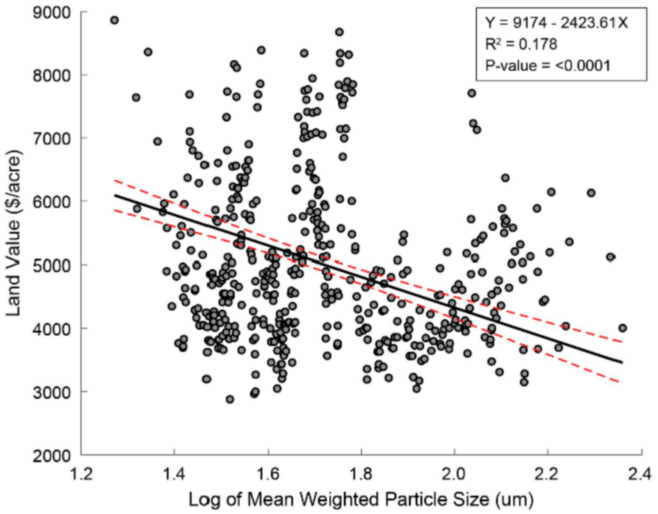

Fig. 8. Scatterplot of land value vs log transformed mean weighted particle size value for the loess at the sampled site.

as 7 m. This amount of uncertainty was statistically unacceptable. In the end, we performed our statistical analyses on a sample of 461 points (Figs. 4, 5). Our final data set had a mean density of one sample every ≈25 km^2.

2.3. *Statistical analyses*

The data were examined using simple least-squares regressions, with land value the dependent variable. We examined both linear and logarithmic regressions.

3. Results and discussion

Across the final data set of 461 sites, loess thicknesses ranged from approximately 10 to 350 cm, with a mean thickness of 86 cm and a median thickness of 70 cm. (We have thickness data from a few sites where the loess is thicker than the length of the 195-cm long auger, because at these sites we performed deep augering oeprations using a Geoprobe machine.) Land values ranged from $2879/acre to $8862/acre, with a mean value of $5019/acre and a median value of $4758/acre. Most of the higher-valued parcels are currently in agriculture, whereas many of the lower-valued parcels and those with thinner loess are in forest or pasture.

3.1. *Statistical analyses*

Whether examined using in a linear or a logarithmic regression, land values generally increase with loess thickness (Fig. 6). Both types of relationships haveP-values well below 0.001.

Obviously, many other factors – cultural and physical - affect land values, besides loess thickness. Nonetheless, the data clearly show that land values are highest in areas of thick loess. Sites with the lowest land values tend to cluster at sites where loess thicknesses are < 100 cm.

Because loess in Wisconsin area can also sometimes be coarse-textured and/or sand-rich (Scull and Schaetzl, 2011; Schaetzl and Attig, 2013; Schaetzl et al., 2018a; Schaetzl et al., 2018b), we also examined the effect of loess texture on land values (Fig. 7). Only linear (non-transformed) regressions are reported for these variables, as the log transformations did not generally improve the statistical relationships.

Table 1
Regression statistics for the entire data set vis-à-vis subsets of the data[1.]

Sample area	No. observations	Regression equation	R2 value of regression equation	P-value	Loess thickness min–max (range) (cm)
Full data set	461	$Y = 3942 + 0.159X$	0.268	<0.001	10–350 (250)
Ten counties in the northwest (NW)	352	$Y = 3890 + 0.102X$	0.237	<0.001	10–350 (250)
Three counties in the southeast (SE)	109	$Y = 5589 + 0.119X$	0.187	<0.001	30–155 (125)
Clark County (NW)	87	$Y = 3576 + 0.069X$	0.112	0.002	20–170 (150)
Chippewa County (NW)	75	$Y = 4056 + 0.092X$	0.229	<0.001	20–307 (287)
Eau Claire County (NW)	63	$Y = 3973 + 0.07X$	0.337	<0.001	10–350 (340)
Columbia County (SE)	56	*$Y = 6659 + 0.057X$*	0.04	0.139	40–174 (134)
Green Lake County	32	$Y = 4863 + 0.124X$	0.559	<0.001	30–185 (155)
Marathon County	31	*$Y = 4723–0.026X$*	0.003	0.759	30–70 (40)
Pierce County	27	$Y = 4727 + 0.101X$	0.285	0.004	30–190 (160)
Fon du Lac County	21	$Y = 4469 + 0.229X$	0.575	<0.001	30–140 (110)
Dunn County	21	$Y = 4123 + 0.083X$	0.215	0.034	25–190 (165)
Wood County	21	*$Y = 4672 + 0.026X$*	0.007	0.723	30–70 (40)
Taylor County	18	*$Y = 3258 + 0.083X$*	0.199	0.063	40–125 (85)
St. Croix County	9	*$Y = 3998 + 0.577X$*	0.127	0.366	35–70 (35)

1. Shown here are equations and data for land value vs reflects the total amount of silt in a 1 cm^2 column from the soil surface down to the base of the loess. We chose this independent variable because, for the full data set, it provided the highest R^2 value. Equations that are NOT significant at $P = 0.05$ are italicized.

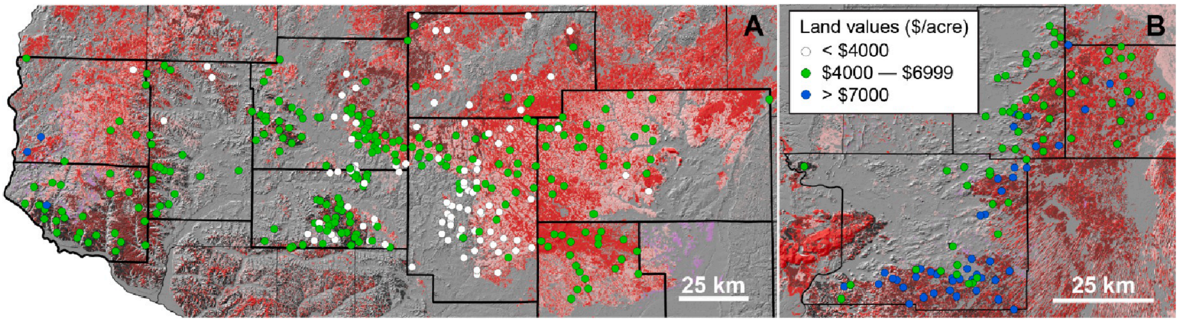

Fig. 9. Maps of the 461 sites that were included in the final data analyses, symbolized by land value.

Usually, sites with siltier loess has higher land values than those with less silt (and typically, more sand). This conclusion is also supported by the negative correlation between mean weighted particle size data and land values (Fig. 8). Parcels on sandier loess are generally of lower overall value.

The data appear to indicate that siltier sites would be in more demand for agriculture or development, perhaps driving the higher land values. Data not shown here indicate that fine and medium silt contents primarily drive this relationship. Knowing this, we then created a variable that reflects the total amount of fine and medium silt in a 1 cm^2 column from the soil surface down to the base of the loess, assuming a bulk density of 1.6 g/cm^3 (Fig. 7C). The regression for this variable yielded the highest R^2 value (0.268) of all the variables examined, clearly indicating that sites with thick, fine-silty loess have the most value across the state of Wisconsin. This conclusion agrees with our observations on the ground, taken while sampling.

Lastly, we performed similar regression exercises on various subsets of the data, to determine if one or more regions or counties were particularly influential in the relationship, or if the relationship falls apart in certain areas. Table 1 provides statistical data for these subsets. We only examined regressions for the most highly correlated variable, i.e., the total amount of fine and medium silt in a 1 cm^2 column from the soil surface down to the base of the loess (Fig. 7C). The data show that as both sample size and the range of loess thicknesses get smaller, the correlations often get weaker. Small sample sizes would have been expected to weaken the relationship, as many other variables affect land value, and for smaller data sets, such factors may overwhelm the effect of loess character (thickness, siltiness) on land value. In our data, five of the nine counties with<60 observations had P-values that were insignificant at the 0.05 level (Table 1). Conversely, all of the three counties with $>$ 60 observations had significant relationships, as did the two breakout regions (NW and SE) (Fig. 4, Table 1). The range of loess thickness values across a region or county also affected the relationship of loess character to land value. Six counties had loess thickness ranges that were $\geq$ 150 cm (Table 1). All six of these counties had a significant statistical relationship between loess thickness and land value. Conversely, of the six counties that had loess thickness ranges $<$ 150 cm, five had insignificant relationships (at $P = 0.05$) (Table 1). Indeed, in Marathon County, where loess is uniformly thin (minimum 30 cm, maximum 70 cm), the regression equation was not only insignificant, but the slope of the best-fit line was slightly negative. Neighboring Wood County, with equally thin loess, exhibited nearly similar statistical results. These data suggest that variation on land values across sites of fairly similar loess thickness are affected more strongly by other factors than loess thickness and texture.

3.2. Spatial analyses

Next, the distribution of sites with high and low scores on the acre-value field was examined, to acquire further insight into the effects of

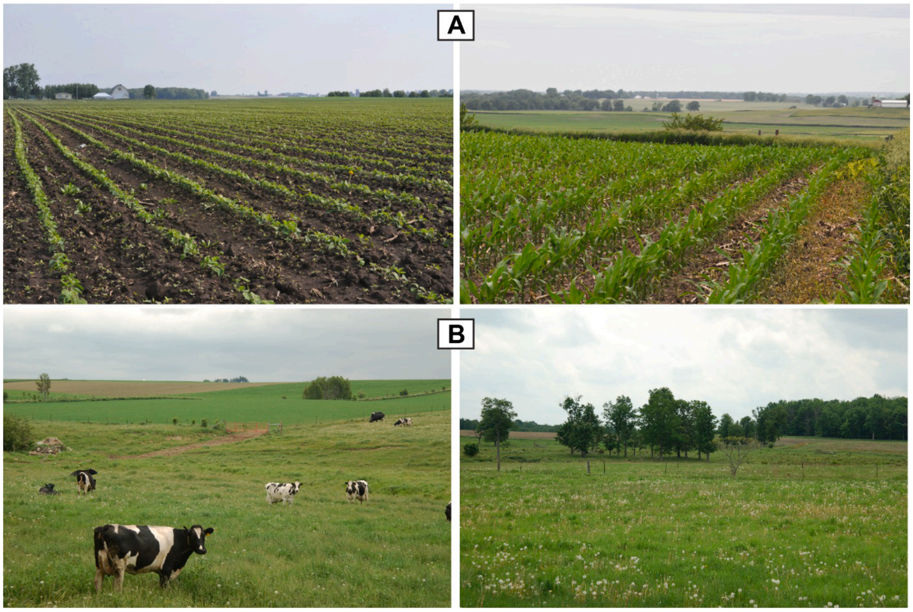

Fig. 10. Images of the typical landscapes and land uses on the loess landscapes of Wisconsin. A. Row crop land uses on the top of a limestone cuesta, with its thick, silty loess cover, in Green Lake County. B. Contrasting landscapes in central Clark County, where the loess is thin and often sandy, and where dairying and pasture are common land uses. Photos by R. Schaetzl.

loess thickness on land valuation. We defined “high” as sites with values > $7000/acre and “low” as sites with values < $4000/acre.

Most of the sites with high land values occur in the southeastern three counties, where loess occurs primarily on top of a broad, limestone cuesta (Jacobs et al., 2011; Fig. 9). Loess on top of the cuesta is silt-rich and thick, and a thriving cash-grain agriculture industry occurs here (Fig. 10). Two other high-value sites are located on the bluffs immediately east of the Mississippi River, in western Wisconsin – again, a thick loess area (Scull and Schaetzl, 2011). In contrast, sites with the lowest values are most common in central Wisconsin, an area of thin loess, where areas of sandy loess are common, especially in western and southern Clark County (Stanley and Schaetzl, 2011). Agriculture in this area is hard-scrabble, with much land being held in pasture for small dairy herds, and woodlots are common (Fig. 10).

In short, our work on the ground is in agreement with what is shown in Fig. 8, and what the scatterplots also suggest (Figs. 6, 7). That is, land values and intensity of agricultural activity and production are in direct proportion to the thickness and siltiness of the loess cover.

4. Conclusions

A variety of physical, cultural, and economic factors can potentially affect the value of land parcels, e.g., soils, topography, drainage class, surrounding land uses and cultural amenities, presence/absence and distance to water bodies, zoning ordinances, local history, quality of schools, proximity to landfills, mines, lakes, etc., and many more. Our study was not designed to evaluate the relative importance and meaningfulness of each of these factors. Rather, we evaluated only one, the physical character of loess, where it exists, on land values. In many locations, as in Wisconsin, loess distributions are patchy and spatially discontinuous, and it is these areas where its affect on land values may be most pronounced.

Among areas with a loess cover, upland land values are highest on sites that have thicker and siltier loess, with the best correlation occurring on a variable that reflects the total mass of fine and medium silt above the underlying sediment. Thus, when other factors are generally left to vary, land owners appear drawn toward, i.e., competition is highest for, sites with thick, silty loess.

In summary, our work has now upheld the longstanding assumption, stated many decades ago by loess researchers of the 19th century, that loess soils (loess ground) are among the most valued, largely because of their inherent high fertilities and lack of other types of restrictions, such as might occur on sites with excessive wetness, or on areas of sandy or clayey soils. Before these researchers even knew how loess was formed, they knew that is was a highly valued soil material, and our data now confirm that observation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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