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Genesis of clay lamellae in golf course soils of Mississippi, USA

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ABSTRACT

Clay lamellae have been observed in the sand putting green soils of a golf course in Mississippi, USA. These lamellae result in reduced water infiltration, saturated soils, and a decline in turfgrass density. The soils featured an A horizon of 4 to 5 cm, mixed A/C horizons of approximately 10 cm, and C horizons of about 30 cm over gravel. The soils were constructed in 2005 with 90% (quartz) sand and 10% (by volume) sand-sized calcined clay over 10 cm of gravel, which was constructed on a subgrade of compacted native soil. Clay lamellae were commonly observed at the interface of sand and gravel, with the exception of a soil profile directly above a drain pipe. Clay contents in the lamellae ranged from 0.10 to 3.8%. We proposed three hypotheses to explain the formation of these lamellae: 1) clay was present in the sand as a construction contaminant and subsequently moved downward, 2) clay originated from the breakdown and subsequent translocation of a calcined soil amendment that was used to construct the soils, or 3) clay from the underlying compacted subgrade moved upwards through the gravel and into the sand. In each hypothesis, clay accumulated at the boundary of sand and gravel due to preferential retention of water in the sand above the gravel. X-ray diffraction showed that the lamellae contained kaolinite and quartz, whereas the calcined soil amendment contained illite and no kaolinite. The underlying subgrade soil contained kaolinite, quartz, and hydroxy-interlayered vermiculite. Discriminant analysis of X-ray fluorescence spectra showed that the clay fractions of these three different samples had unique chemical fingerprints. These findings suggest that the lamellae did not likely originate from the calcined soil amendment or the subgrade soil. We propose that they originated from clay that was initially present in the sand, which was translocated downwards. This study provides evidence for formation of lamellae in $<$10 years, and provides an example of accelerated soil formation due to anthropogenic factors.

1. Introduction

Urban and anthropogenic soils are characterized by alteration and disturbance from human activities. The distribution of human-influenced soils can be approximated by the distribution of global population (Capra et al., 2015). An estimated 3% of the world's land area is considered urbanized (Liu et al., 2014). There has been an increased research focus on urban soils, with most research focusing on pollution and contamination (e.g., Li et al., 2013; Luo et al., 2015). There have been numerous studies describing or modelling pedogenesis in urban and anthropogenic soils (Huot et al., 2013; Leguédois et al., 2016; Scalenghe and Ferraris, 2009; Séré et al., 2010).

Turfgrass is one of the largest irrigated crops in the USA on the basis of land area, and most turfgrass is found in densely populated areas (Milesi et al., 2005). Turfgrass soils have altered topography and receive inputs including water, fertilizer, and various amendments such as calcined clay and peat to improve water- and nutrient-holding capacity. There are over 16,000 golf courses (Beard, 2002) in the USA, and these cover a land area of approximately 4850 km^2 (Throssell et al., 2009). The soils of golf course putting greens are engineered and constructed with materials that were excavated, transported, and repositioned across the landscape. Many putting green soil profiles are constructed with a 30 cm layer of sand over 10 cm of gravel (e.g. U.S. Golf Association, 2004). Sand is a favorable soil medium because it drains quickly and is not easily compacted. The gravel layer creates a hanging water column to improve water retention in the soil between rainfall or irrigation events (Prettyman and McCoy, 2003; Taylor et al., 1997). Few pedological investigations have been conducted on constructed golf putting green soils, despite their extent and economic importance.

In 2013, we visited a golf course in Vancleave, Mississippi where the turfgrass on putting greens was thinning and the soil was waterlogged, and thin lamellae had accumulated at the boundary of sand and gravel. This appeared comparable to previous observations of iron-cemented layers that occurred at textural boundaries in putting green soils (Obear et al., 2014). The objective of the present study was to explain the genesis of clay lamellae occurring in soil profiles from a putting green of this Mississippi golf course based on the distribution of clay, SOC, Fe, and pH by depth and determine how these properties were affected by topography. From these observations, we formulated and tested hypotheses to explain the formation of clay lamellae in putting green soils.

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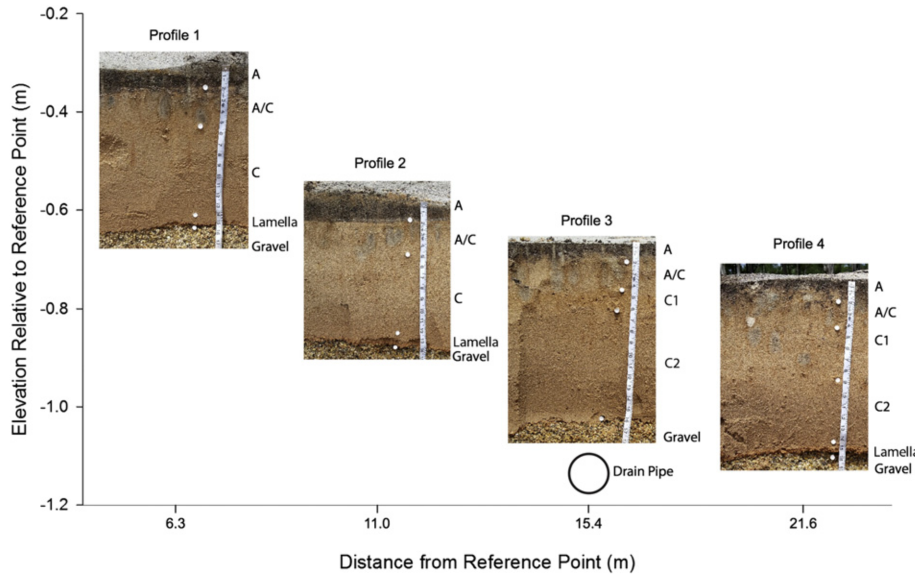

Fig. 1. Four soil profiles with horizon designations across a linear topographic transect, with depth and distance relative to an arbitrary reference point adjacent to the putting green. Profile 3 was directly above a drain pipe. Size scale on profile images is shown in inches.

2. Materials and methods

2.1. Site characteristics

Samples were collected from a putting green at The Preserve Golf Course in Vancleave, MS, USA. Mean annual precipitation from January 2004 to January 2014 in this area was 1332 mm, and mean annual ET was estimated to be 1270 mm. During this same period, the mean monthly air temperature ranged from 5 °C to 34 °C (NCDC, 2016). The putting green soils at this site were constructed in 2005 based on the recommendations of the United States Golf Association (2004), featuring a 30 cm layer of primarily medium quartz sand over a layer of gravel, above a compacted subgrade comprised of the soil from the site. In the subgrade, the A horizon was removed during construction, and the B horizon was graded and sloped to direct water to a drain pipe system which was installed in a 10 cm-deep gravel-filled trench. The native subsoil was a Smithton loam (Coarse-loamy, siliceous, semiactive, thermic Typic Paleaquults) (Soil Survey Staff, Natural Resource Conservation Service, United States Department of Agriculture). The sand had a quartz mineralogy and was sourced from a pit in Perkinston, MS (Perkinston Sand and Gravel Co, Perkinston, MS, USA). The sand was amended with a 1.0 to 2.4 mm diameter calcined material manufactured from kiln-fired silica, montmorillonite, and illite (Profile Products LLC, Buffalo Grove, IL) during construction at a ratio of 10%

Table 1
Soil profile descriptions, clay, and volumetric water content for the studied soils.

Profile	Horizon	Depth cm	Dry color	Moist color	Comments	Dry cons.	Cementation	VWC[a] %
	A	0–5.1	2.5 YR 7/2	2.5 YR 5/2	–	L	NC	8.1
	A/C	5.1–12.7	7.5 YR 8/2	7.5 YR 7/4	Mottles[b] 7.5 YR 6/8	L	NC	9.0
	C	12.7–36.8	7.5 YR 8/4	7.5 YR 6/4	–	L	NC	12.5
	Lamella	36.8–38.1	7.5 YR 8/6	7.5 YR 6/8	–	SH	EW	22.3
	Gravel	38.1–48.3				L	NC	2.7
2	A	0–3.8	2.5 YR 8/2	2.5 YR 6/4	–	L	NC	8.5
	A/C	3.8–12.1	7.5 YR 8/4	7.5 YR 5/4	Mottles[b] 7.5 YR 6/8	L	NC	9.0
	C	12.1–30.5	7.5 YR 8/4	7.5 YR 6/6	–	L	NC	12.5
	Lamella	30.5–34.3	7.5 YR 8/6	7.5 YR 5/8	–	L	EW	16.0
	Gravel	34.3–44.5				L	NC	2.7
3	A	0–3.8	2.5 YR 6/2	2.5 YR 5/2	–	L	NC	10.5
	A/C	3.8–10.2	7.5 YR 8/2	7.5 YR 5/4	Mottles[b] 7.5 YR 6/8	L	NC	8.5
	C1	10.2–14.6	7.5 YR 8/4	7.5 YR 5/6	Mottles 7.5 YR 6/8	L	NC	8.5
	C21[c]	14.6–38.7	7.5 YR 8/4	7.5 YR 6/6	–	L	NC	17.9
	C22[c]	38.7–41.3	7.5 YR 8/4	7.5 YR 6/6	–	L	NC	29.7
	Gravel	41.3–48.3				L	NC	3.6
4	A	0–4.4	2.5 YR 6/2	2.5 YR 5/2	–	L	NC	11.5
	A/C	4.4–10.2	7.5 YR 8/2	7.5 YR 5/4	Mottles[b] 7.5 YR 6/8	L	NC	9.0
	C1	10.2–24.8	7.5 YR 8/4	7.5 YR 6/4	–	L	NC	9.0
	C2	24.8–35.6	7.5 YR 8/4	7.5 YR 6/6	–	L	NC	26.7
	Lamella	35.6–39.4	7.5 YR 8/6	7.5 YR 6/8	–	SH	EW	30.6
	Gravel	39.4–47.0				L	NC	3.6

[a] Volumetric water content measured on the date of sampling.
[b] Mottles surrounded channels of sand that were introduced during core aeration events.
[c] Despite a lack of visual horizonation, the bottom 2.6 cm of the profile was sampled to confirm the absence of a lamella.