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Soils with iron-cemented layers on golf courses in the USA

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ABSTRACT

Layers cemented by iron and manganese have been observed in soils of putting greens at golf courses throughout the USA. They result in reduced water infiltration, saturated conditions in the root zone, and a decline in turfgrass density and quality. The physical and chemical properties of these layers have not been investigated nor described in detail. Here we present a detailed analysis of the physicochemical properties and a conceptual pedogenetic model for the formation of Fe-cemented layers in soils of golf putting greens across the USA. These man-made soils have an A horizon of about 5 to 10 cm over 20 to 30 cm sand (C horizon) over gravel. The Fe-cemented layer is commonly found at the interface of the A and C horizons, or the C horizon and the gravel layer. Levels of total Fe in the cemented layers range from 0.41 to 16.21 g kg^{-1} and these are accompanied by accumulations of SOC and sometimes high levels of Mn and Al. The downward movement of water (irrigation), high levels of Fe (fertilization), and a textural discontinuity are key factors in the formation of the Fe-cemented layer. The layers may form at rates as high as 1.5 mm per year depending on Fe content and redox conditions in the root zone, and may become cemented in 10 years. These cemented layers meet the criteria of the placic horizon in *Soil Taxonomy*.

1. Introduction

Most soils in urban areas have been altered by human activities including moving, draining, paving or other forms of disturbance. In recent years, there is an increased interest in the soils of urban areas which is primarily driven by studies on pollution and environmental issues (e.g. Andersson et al., 2010; Li et al., 2013). Considerable research on urban soils is also conducted in relation to peri-urban and urban agriculture (Materechera, 2009; McClintock, 2012). Lawns and gardens often receive inputs (including fertilizer, water, and pesticides) and such soils have been significantly disturbed, but comprise the natural soil of the area. Soils of golf course putting greens also receive inputs but these soils are constructed like the soils of mine spoils; the materials are excavated, transported, and repositioned across the landscape.

In the USA, there are over 16,000 golf courses (Beard, 2002) covering a land area of approximately 4850 km^2 (Throssell et al., 2009). On a typical golf course, about one-quarter of the total land area is comprised of intensively managed turfgrass (putting greens, tees, or fairways). Putting greens are intensively managed with daily mowing at heights of less than 3 mm and frequent fertilization and irrigation. Considerable research has been conducted regarding the optimal root zone construction for golf putting greens (Bigelow and Soldat, 2013). Putting green soil profile designs include a 30 cm sand root zone over gravel (e.g. USGA, 2004). The sand layer is needed for its resistance to compaction and improved drainage, whereas the layer of gravel allows the root zone to retain pore water between rainfall events (Prettyman and McCoy, 2003; Taylor et al., 1997).

Much of the research on soils of golf courses is focused on nutrient and water-use efficiency. Very few pedological investigations have been done on these constructed and engineered soils despite their extent and economic importance. In 2008, we noted areas on the putting greens of golf courses in Hawaii where the turf was dead or poorly growing and the soil was waterlogged. Soil pits revealed a Fe-cemented layer at the boundary of the sandy subsoil and the gravel. These features have not been researched previously, which prompted us to investigate how and where they form. The objectives of our research were to investigate in detail the physicochemical properties and processes of Fe-cemented layer formation in golf course putting green soils across the USA.

2. Materials and methods

2.1. The sites

In total 24 sites were identified that had putting green soils with Fe-cemented layers (Fig. 1). The soils were identified through

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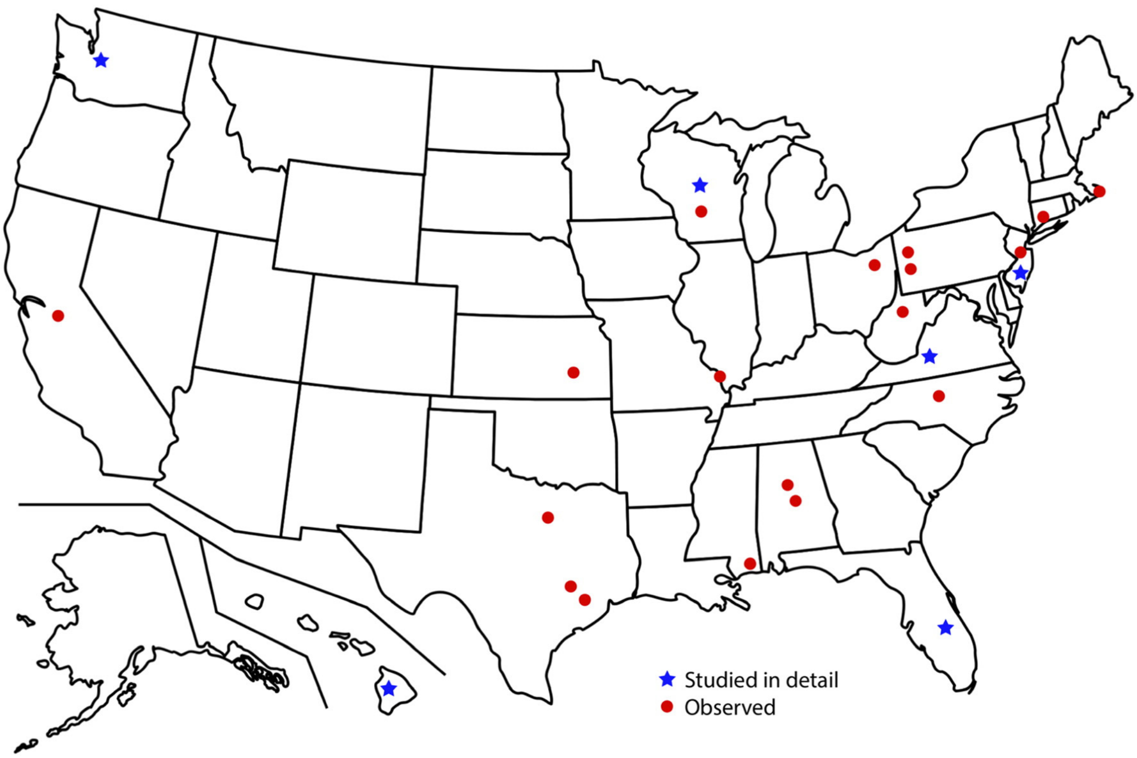

Fig. 1. Presence of Fe-cemented layers in golf course putting greens in the USA. Red circles indicate observed sites ($n = 18$) and blue stars are the sites studied in detail ($n = 6$).

communication with other researchers, golf course superintendents, and US Golf Association Green Section agronomists. Of these 24 sites, 6 were chosen for detailed study and analysis and they represent a range in course age, geographic location, and climate (Table 1). Each of these sites featured putting greens with a sand root zone over gravel, which is commonly referred to as a two-tiered construction. In this paper, the 6 sites are identified by the state in which they are located: New Jersey, Washington, Virginia, Florida, Wisconsin, and Hawaii.

Fig. 2 shows putting greens from Hawaii (A) and Wisconsin (B–D) that have the typical Fe-cemented pan with depth. The low-lying depositional area of a putting green in Wisconsin was excavated to uncover the layer at the interface of sand and gravel (B). A different soil profile from Wisconsin (C) shows a weakly-cemented pan at the lower interface of an organic-rich surface layer (10 cm depth), and at the boundary of sand and gravel (35 cm depth).

2.2. Soil sampling and analysis

At each of the 6 sites, 3 soil profile samples were collected from a low-lying area of one putting green as it was observed that cemented pan layers were more prevalent in low-lying areas of putting greens. One representative profile sample from a low-lying area of each site was chosen for further analysis. From golf courses in Wisconsin and Hawaii, profile samples were also taken from a well-drained area (referred to as “High”) and compared to the samples from the low-lying area (referred to as “Low”) to evaluate within-site variation. Profile soil samples were collected in PVC pipes (5 cm diameter, 50 cm length) that were sharpened on the bottom and driven into the soil with a rubber mallet. All of the samples were taken from the soil surface to 5 to 7 cm below the depth of the gravel drainage layer. The site in Florida was in the midst of renovation and at this site only the bottom 21–38 cm of the profile was sampled.

The sampling pipes were split vertically with an oscillating saw, and soil horizons were delineated based on visual characteristics including wet and dry color (Munsell), dry consistency, cementation, and presence or absence of plant roots and mottles. Horizons were named according to the Keys to Soil Taxonomy (Soil Survey Staff, 2010). To capture physicochemical changes, horizons between 15 and 23 cm in thickness were split in half, and horizons thicker than 23 cm were split into thirds.

Table 1
Study sites of two-tiered putting greens with a sand-based root zone over a gravel drainage layer. Climatic data represent means from February of 1981 through November of 2012.

Site ID	Lat.	Long.	Elev. masl	MAP mm	Mean max. temp. °C	Mean min. temp. °C	Age of root zone years	Turfgrass species
Washington	48°N	−122°W	133	796	15.4	7.2	15	*Agrostis stolonifera*, *Poa annua*
Wisconsin	45°N	−90°W	340	682	11.9	1.4	35	*Agrostis stolonifera*, *Poa annua*
New Jersey	40°N	−74°W	34	883	18.1	6.8	25	*Agrostis stolonifera*, *Poa annua*
Virginia	37°N	−80°W	323	915	19.7	8.2	14	*Agrostis stolonifera*
Florida	26°N	−80°W	4	1345	28.1	19.4	16	*Cynodon dactylon* × *transvaalensis*
Hawaii	20°N	−156°W	31	276	29.4	21.3	9	*Paspalum vaginatum*

MAP: mean annual precipitation. Climatic data from National Climatic Data Center. Date of access: 13 September, 2013 (www.ncdc.noaa.gov/cdo-web/datasets).
masl: meters above sea level.
Hawaii data from Western Regional Climate Center. Date of access: 13 September, 2013 (www.wrcc.dri.edu/).