TURFGRASS

Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data

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ABSTRACT

As part of the urbanization process, an increasing percentage of land throughout the USA is being converted into turfgrass. Because of high productivity and lack of soil disturbance, turfgrass may be making substantial contributions to sequester atmospheric C. To determine the rate and capacity of soil C sequestration, we compiled historic soil-testing data from parts of 15 golf courses that were near metropolitan Denver and Fort Collins, CO, and one golf course near Saratoga, WY. In addition, we compiled a total of about 690 data sets on previous land use, soil texture, grass species and type, fertilization rate, irrigation, and other management practices. The oldest golf course was 45 yr old in 2000, and the newest golf course was 1.5 yr old. Nonlinear regression analysis of compiled historic data indicated a strong pattern of soil organic matter (SOM) response to decades of turfgrass culture. Total C sequestration continued for up to about 31 yr in fairways and 45 yr in putting greens. However, the most rapid increase occurred during the first 25 to 30 yr after turfgrass establishment, at average rates approaching 0.9 and 1.0 t ha^{-1} yr^{-1} for fairways and putting greens, respectively. Our study also found that past land use imparted a strong control of SOM baseline; fairways converted from agricultural lands exhibited 24% lower SOM than fairways converted from native grasslands. We concluded that C sequestration in turf soils occurs at a significant rate that is comparable to the rate of C sequestration reported for USA land that has been placed in the Conservation Reserve Program.

THROUGHOUT THE USA, urban landscapes are continuing to expand onto former farms, pastures, and native areas. As part of the urbanization process, an increasing percentage of land throughout the USA is being converted into turfgrass, such as home lawns, parks, commercial landscapes, recreational facilities, golf courses, and other greenbelts. Currently, turfgrasses occupy about 20 million ha in the USA, and the area is expanding (Anonymous, 1996). This amount of land area exceeds the 14.7 million ha enrolled under the USDA Conservation Reserve Program (CRP) (Follett et al., 2001) and is equivalent to about 14% of the 141 million ha of privately owned, cultivated cropland in the USA (Natl. Agric. Stat. Serv., 1997).

Understanding soil organic matter (SOM) dynamics in turfgrass systems is of great importance. First, SOM is recognized as having profound influence on ecosystem sustainability, soil fertility, and soil structure (Tabatabai, 1996). Soil organic matter content is also of particular interest to turf managers because (i) changes in SOM influence the air-filled porosity, water retention, and percolation in the sand-based root zone, which is used intensively in putting greens, tees, and sports fields and (ii) SOM serves as a major repository and reserve of plant nutrients, especially N, P, S, and K.

Recent global concerns over increased atmospheric CO_2, which can potentially alter the earth's climate systems, have resulted in rising interest in studying SOM dynamics and C sequestration capacity in various ecosystems (Schlesinger, 1999). Determination of C pools in urban turfgrass soils will shed light on the role of turfgrass systems in contributing to terrestrial C sequestration.

To study SOM dynamics, measurements over years and decades are necessary because changes in SOM occur slowly and annual changes are generally small. Historic data may be most effective in assessing C sequestration in urban turfgrass lands. Many golf courses analyze soils (including SOM measurement) on a yearly basis and possess long-term soil-testing results. Long-term climate records, documented management activities, and soil data are also available for many well-managed golf courses. Such information is invaluable in revealing the dynamics of SOM, assessing C sequestration, and interpreting soil C changes in golf courses.

The purposes of the study reported here were to (i) conduct a survey to compile data on soil-testing results from different golf courses in chronosequences, spanning a wide range of duration of turf management to examine the SOM dynamics in golf courses and (ii) generate regression models to predict the rate of SOM changes and to help identify factors important to C sequestration.

MATERIALS AND METHODS

During 2000, 12 golf courses around the Denver, CO, metropolitan area; three golf courses around the Fort Collins and Loveland, CO, area; and one golf course in Saratoga, WY, were surveyed, and the available soil-testing results from these golf courses over time were compiled (Table 1). Parameters of each soil sample tested included mineral content (Ca, Mg, K, and Na), cation exchange capacity (CEC), SOM, and pH.

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Abbreviations: CEC, cation exchange capacity; CRP, Conservation Reserve Program; SOC, soil organic carbon; SOM, soil organic matter.

The oldest golf course was 45 yr old in 2000; the newest golf course was 1.5 yr old.

Concurrent with our compilation of the soil data, we also collected information on prior land use, grass species and type, irrigation, mowing height and frequency, fertilization, and other cultivation applied. Ten courses with ages ranging from 4 to 45 yr were established on native prairie, five courses with ages ranging from 1.5 to 35 yr were established on agricultural land, and one course (5 yr old) was built on mixes of native and agricultural lands. Turfgrasses grown in putting greens were creeping bentgrass (*Agrostis palustris* Huds.) or a mixture of creeping bentgrass and annual bluegrass (*Poa annua* L.). Turfgrasses grown on fairways and tees were perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.), or a mixture of both. At all survey sites, irrigation was provided at approximately 75 to 100% of evapotranspiration since turf establishment. In the fairway sites, existing soils were subjected to shaping and topsoil replacement before establishment. Soil series, surface texture, and taxonomic classification for the 14 sites used in the fairway data (Table 2) were obtained with the assistance of the Natural Resources Conservation Service (NRCS) of the USDA. All of the golf courses were in a mesic soil temperature regime (Soil Survey Staff, 1998) except Old Baldy, which was in a frigid soil temperature regime. Most of the green and tee sites were made from about 30 cm of sand that was placed over a gravel layer or the existing soil based on standard construction methods of golf course greens and tees. Exceptions were greens in Valley Country Club and the Olde Course at Loveland where the greens were originally established on existing soil. After establishment, approximately 15 cm of sand was added at the top over time through topdressing.

A total of ≈690 data sets were compiled: Twenty-six samples were tested by Servi-Tech Laboratories, Dodge City, KS[1]; 90 samples from the Old Baldy Golf Course were tested by the Soil, Water, and Plant Testing Laboratory at Colorado State University, Fort Collins, CO; and 574 soil samples were tested by Brookside Laboratories, New Knoxville, OH. The soil-testing labs provided information on analytical methods. In Brookside, soils were extracted using the Mehlich 2 extractant developed by Mehlich (1984). Soil cations were determined by inductively coupled plasma–atomic emission spectroscopy (ICP–AES) instrumentation. In Servi-Tech Lab, the Na^+, Ca^{2+}, Mg^{2+}, K^+ were extracted with 1 *M* ammonium acetate

Table 1. Description of experimental sites (golf courses) participated in the study.

Experimental site	Years since establishment†	Prior land use
Rolling Hill Country Club	31	Native grassland
Ptarmigan Country Club	13	Native grassland
Boomerang Links	10	Agricultural land
Valley Country Club	45	Native grassland
Inverness Golf Club	26	Native grassland
Hiwan Country Club	38	Native grassland
Murphy Creek Golf Course	2	Agricultural land
Boulder Country Club	35	Native grassland
Springhill Golf Course	22	Agricultural land
The Olde Course at Loveland	35	Agricultural land
Cattail Creek Golf Course	9	Native grassland
Plum Creek Golf and Country Club	16	Native grassland
Westwoods Golf Course	8	Native grassland
River Valley Ranch Golf Club	5	Agricultural land
Saddle Rock Golf Course	5	Native or agricultural land
Old Baldy Golf Course	37	Native grassland

† Average years since establishment = 21.

[1] Trade and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment by the authors or the USDA.

Table 2. Classification and surface texture of principle soil series sampled by experimental site.

Experimental site	Principle soil series	Surface texture classification	Taxonomic classification
Rolling Hill Country Club	Loveland	Clay loam	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, calcareous, mesic Fluvaquentic Endoaquolls
Ptarmigan Country Club	Table Mountain	Loam	Fine-loamy, mixed, superactive, mesic Pachic Haplustolls
	Paoli	Loam	Course-loamy, mixed, superactive, mesic Pachic Haplustolls
	Caruso	Loam	Fine-loamy, mixed, mesic Fluvaquentic Haplustolls
Boomerang Links	Olney	Loamy sand	Fine-loamy, mixed, superactive, mesic Ustic Haplargids
	Otero	Sandy loam	Coarse-loamy, mixed, superactive, calcareous, mesic Aridic Ustorthents
	Nelson	Fine sandy loam	Coarse-loamy, mixed, superactive, calcareous, mesic Ustic Torriorthents
Valley Country Club	Renohill	Clay loam	Fine, smectitic, mesic Ustic Haplargids
	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
Inverness Country Club	Renohill	Clay loam	Fine, smectitic, mesic Ustic Haplargids
	Fondis	Silt loam	Fine, smectitic, mesic Aridic Paleustolls
Murphy Creek Golf Course	Renohill	Clay loam	Fine, smectitic, mesic Ustic Haplargids
	Fondis	Silt loam	Fine, smectitic, mesic Aridic Paleustolls
Boulder Country Club	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
Springhill Golf Coarse	Fondis	Silt loam	Fine, smectitic, mesic Aridic Paleustolls
	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
The Olde Coarse at Loveland	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
	Fort Collins	Loam	Fine-loamy, mixed, superactive, mesic Aridic Haplustalfs
Cattail Creek Golf Coarse	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
	Fort Collins	Loam	Fine-loamy, mixed, superactive, mesic Aridic Haplustalfs
Plum Creek Golf & Country Club	Fondis	Silt loam	Fine, smectitic, mesic Aridic Paleustolls
	Bresser	Sandy loam	Fine-loamy, mixed, superactive, mesic Aridic Argiustolls
Westwoods Golf Coarse	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
	Ulm	Clay loam	Fine, smectitic, mesic Ustic Haplargids
Saddle Rock Golf Coarse	Nunn	Clay loam	Fine, smectitic, mesic Aridic Argiustolls
Old Baldy Golf Coarse	Ryan Park	Sandy loam	Coarse-loamy, mixed, superactive, frigid Ustic Haplargids
	Blackhall	Fine sandy loam	Loamy, mixed, superactive, calcareous, frigid, shallow Ustic Torriorthents

Table 3. Regression equations obtained using stepwise analyses for soil organic matter.

Variable	Parameter	Standard error	Sum square	*F*-value	*P*-value
		Fairways [R^2 = 0.67, $C(p)$ = 2.7, n = 190]			
Intercept	3.36	0.69	8.3	19.28	0.0001
Age (X)	0.117	0.0212	13.2	30.6	0.0001
X^2	−0.0014	0.0004	4.04	9.4	0.003
pH	−0.049	0.143	4.95	11.5	0.03
K, mg kg^{-1}	0.002	0.0004	8.87	20.6	0.0001
Na, mg kg^{-1}	−0.0017	0.0004	5.53	12.8	0.0004
		Putting green [R^2 = 0.83, $C(p)$ = 5.2, n = 245]			
Intercept	1.833	0.71	1.89	6.66	0.01
Age (X)	0.116	0.0158	15.31	53.8	0.0001
X^2	−0.0014	0.0003	5.76	20.26	0.0001
CEC	0.140	0.0176	0.053	6.99	0.01
CEC^2	−0.0038	0.002	1.043	3.67	0.05
pH	−0.289	0.091	2.84	9.99	0.002
Na, mg kg^{-1}	0.0044	0.001	5.54	19.48	0.0001

and measured by ICP–AES instrumentation (Black, 1965). Cation exchange capacity is calculated using the summation method. At Colorado State University, the mineral content (Ca, Mg, K, and Na) was not determined. In all labs, soil organic C (SOC) was determined by reaction with $Cr_2O_7^{2-}$ and sulfuric acid. The remaining unreacted $Cr_2O_7^{2-}$ is titrated with $FeSO_4$ using ortho-phenanthroline as an indicator, and oxidizable organic C was calculated by the difference in $Cr_2O_7^{2-}$ before and after reaction (Nelson and Sommers, 1982). Soils were sampled to a depth of 11.4 cm, except for the fairways in the Old Baldy Golf Course where the soil was sampled to a depth of 15.2 cm. Data were reported as percentage of SOM. The bulk density of soil was not measured.

Data Analysis

Nonlinear regression analysis was performed to evaluate the changes in SOM content over time after establishment of turf in putting greens and fairways. Data from the Old Baldy Golf Course fairways were analyzed and presented separately because of the difference in sampling depth. Stepwise regression and correlation analyses were performed to relate SOM to other soil test variables and management regimes (Table 3). When appropriate, prior land use effect and other management effects were determined by analysis of variance (SAS Inst., 1991). Means were separated using Fisher's protected LSD.

RESULTS AND DISCUSSION

Soil Organic Matter Changes and Carbon Sequestration in Fairways and Putting Greens

Nonlinear regression analysis indicated a strong pattern of increase in SOM in response to decades of turfgrass culture and that a segmented (quadratic with plateau) model best described the changes of SOM over 0 to 45 yr after turfgrass establishment (Fig. 1A and 1B). Before SOM reached equilibrium, the relationship between SOM and years after turf establishment was quadratic; after reaching equilibrium, SOM did not change over time under continued turfgrass management.

The regression shows that SOM of putting greens was 0.6% at 1 yr after turfgrass establishment and then increased to 2.7% at 20 yr after establishment and to 3.4% at 30 yr after establishment. The time required for

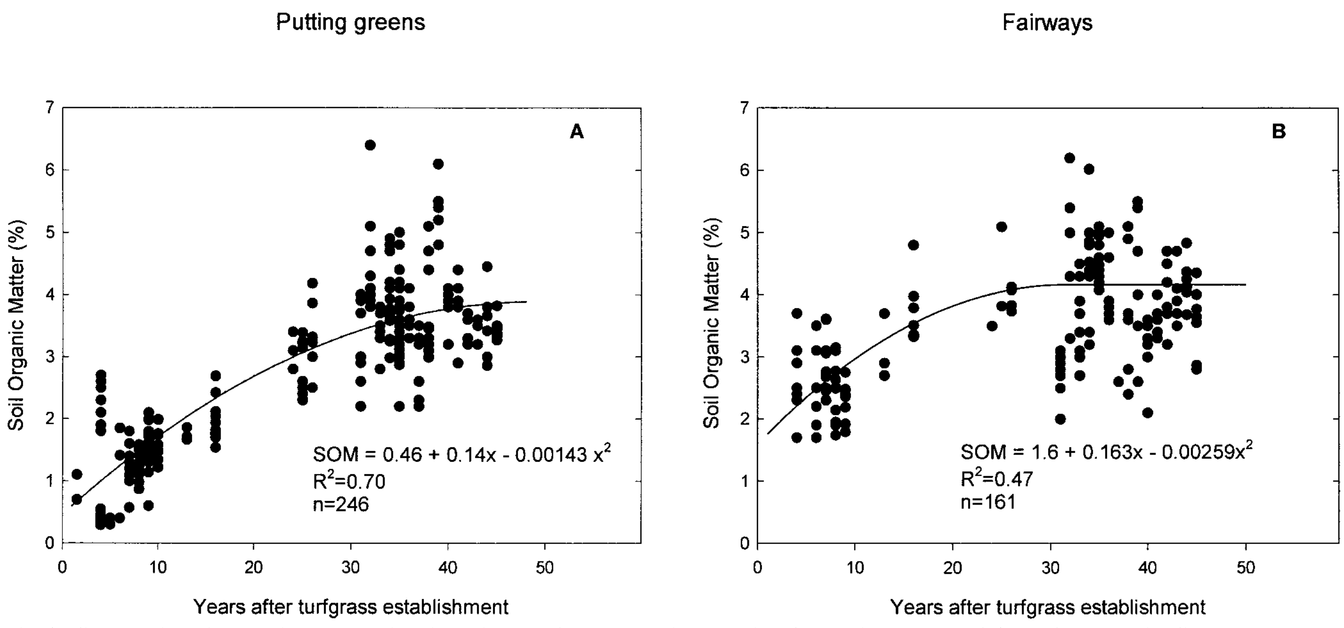

Fig. 1. Changes in soil organic matter with time since turfgrass establishment in (A) putting greens of 16 golf courses in Colorado and (B) fairways of 13 golf courses in Colorado. Data were based on soil-testing results from these golf courses sampled to 11.4-cm depth.

SOM degradation and formation to reach equilibrium (3.9% SOM) was 45 yr in putting greens. The SOM of fairways was 1.76% at 1 yr after turfgrass establishment, which increased to 3.8% at 20 yr after establishment and 4.2% at 30 yr after. The time for SOM to reach equilibrium (4.2%) was 31 yr in fairways. This period is consistent with estimates by Lal et al. (1998) that achieving a practical limit to soil C sequestration in croplands with improved practice may require as much as 50 yr.

Putting greens are established on sand, which has lower initial SOM than fairways (0.6 vs. 1.76%). The initial low SOM, along with soil aeration and sand topdressing as regular putting green management practices, may have prolonged the time required for SOM to reach equilibrium. The uniform condition on putting greens appears to have limited many confounding factors, such as soil texture, soil uniformity, variability of the initial soil SOM, and prior land use. This may have resulted in the relatively high correlation coefficient ($R^2 = 0.72$) observed in putting greens (Fig. 1A). Although the increase in SOM continued for a shorter period (31 yr), fairways accumulated a higher level of SOM at equilibrium than did putting greens (4.2 vs. 3.9%), indicating a higher capacity for C stabilization in the loams and heavier-textured soils in the fairways (Fig. 1B).

Assuming that SOC comprises 58% of SOM mass and that all sites have a uniform bulk density (1.6 and 1.5 g cm^{-3} for putting greens and fairways, respectively; these values were the averages of samples from three golf courses participated in this study), total C sequestration rates in fairways and putting greens ranges between 0.9 and 1.0 t ha^{-1} yr^{-1} during the first 25 to 30 yr after turfgrass establishment. We recognize that soil bulk densities are not uniform. However, our estimate is similar to the findings of Gebhart et al. (1994), who reported that C sequestration rate is 1.1 t ha^{-1} yr^{-1} after temperate cultivated land is converted to perennial grasslands. Post and Kwon (2000) compiled literature data for soil C in areas where grasslands have been allowed to develop on previously disturbed lands and reported that the average rates of C accumulation during the early aggrading state of grassland establishment are 0.33 t ha^{-1} yr^{-1}. The greater C accumulation found in our study likely resulted from fertilization and irrigation inputs for these highly managed grasslands.

In this study, soils were only sampled to 11.4 cm. Due to the regular mowing, turfgrass root systems are concentrated at surface 10- to 15-cm depth (Qian et al., 1997). However, if deep C sequestration does occur, our above estimates would be conservative, and the estimated period of potential sequestration would be longer. Research on other grassland systems, such as CRP, show that C sequestration is occurring to depths of 20 cm and deeper within 5 to 10 yr (Follett et al., 2001; Gebhart et al., 1994).

Rates of sequestration during early years after turf establishments were more rapid. These rates are comparable to or exceed those reported for U.S. land that has been placed in the CRP (Follett et al., 2001). Carbon sequestration depends upon primary production, rate of biomass decomposition, and the percentage of primary production that enters long-term storage. Regularly mowed turfgrass is a highly productive ecosystem (Hull, 1992). Falk (1976) estimated that belowground biomass in a typical Kentucky bluegrass turf ranged from 1610 g m^{-2} in the summer to 911 g m^{-2} in the spring. Turfgrasses are perennial and subjected to minimal soil disturbance (such as tilling) after establishment, which is a critical factor for C sequestration. However, turfgrass does receive substantial management inputs, including irrigation, mowing, and fertilization. These management practices may increase the biomass decomposition in turfgrass systems. Falk (1976) found that the root turnover time is 2.4 yr for a Kentucky bluegrass lawn at 0 to 7.6 cm, which is substantially faster than other grassland ecosystems. The characteristics of turf systems, including high production and high root turnover, may explain the high C sequestration rate and fast pace to reach equilibrium in turfgrass systems. Studies in pasture lands indicate SOM increase can continue for as long as 40 to 60 yr (Barrow, 1969; Potter et al., 1999).

Previous Land Use and Soil Organic Carbon Content in Golf Courses

To determine the effect of prior land use on SOM in turfgrass, comparisons were made for land converted to golf courses (during the past 10 yr) from agricultural land vs. native grassland. The previous land use of Murphy Creek Golf Course, Boomerang Links, River Valley Ranch Golf Club, and parts of Saddle Rock Golf Course was agricultural, whereas those of Plum Creek Golf and Country Club, West Woods Golf Course, and parts of Saddle Rock Golf Course were native shortgrass prairie. The SOM of native grasslands and agricultural lands before golf course establishment was not measured, and SOM content in the surface 11.4 cm was likely significantly changed due to golf course construction. Results of *t*-test comparison indicated that fairways converted from agricultural lands exhibited 24% lower SOC than fairways converted from native grasslands (Fig. 2). Thus, past land use imparted a strong control of the SOM baseline. Numerous studies have demonstrated that intensive agricultural practices result in oxidative losses of SOC (Haas and Evans, 1957; Wilson, 1978). In Texas, Potter et al. (1999) reported that SOC in the surface

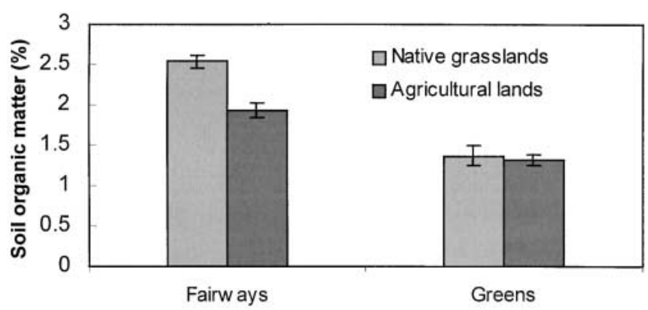

Fig. 2. Influence of past land use on soil organic matter in the surface (11.4 cm) soil of fairways and putting greens. Turf was <10 yr old. Vertical lines represent standard errors.

120 cm of the agricultural soil was 25 to 43% less than that of native prairie sites. The initial soil chemical, physical, and biological conditions in fairways in previous native grasslands may benefit the fairway management compared with fairways established on agricultural lands, in terms of plant nutrient reserves and nutrient-cycling capacity.

In contrast to fairways, prior land use had little influence on SOM in putting greens (Fig. 2). This is not surprising because putting greens were established at the top of the newly added, sand-based medium.

The Old Baldy Golf Course

Among the golf courses studied, fairway data points for the Old Baldy Golf Course were offset along the time axis compared with those from the other fairways (Fig. 3 vs. Fig. 1B). Data from 90 soil test results for the Old Baldy Golf Course were available from 18 to 34 yr following its establishment, during which time the rate of increase was 0.1% SOM yr^{-1}. For the remaining fairways (Table 1), the rate of increase was also about 0.1% SOM yr^{-1} for the linear part of the curve in Fig. 1B that extends from 2 to about 24 yr. The intercept of the line (0.17% SOM) indicates that the initial amount of SOM in the soil for this golf course was quite low (Fig. 3). We are unsure of the reasons for the offset along the time axis for the Old Baldy Golf Course compared with the others. Possible explanations include a slightly greater sampling depth (15.2 vs. 11.2 cm) and an aggressive soil aeration program between 15 to 17 yr after turf establishment (to control the excessive thatch). The intensive aeration may have resulted in more rapid oxidation of SOM. Another possible consideration is that the course is in a frigid soil temperature regime. However, data from 18 to 34 yr following its establishment showed that consistent management is now being supplied and SOM content is increasing at a nearly identical rate as for the other golf courses, indicating that the sequestration of soil C in these soils may reach a similar level to that of the other fairways in this study.

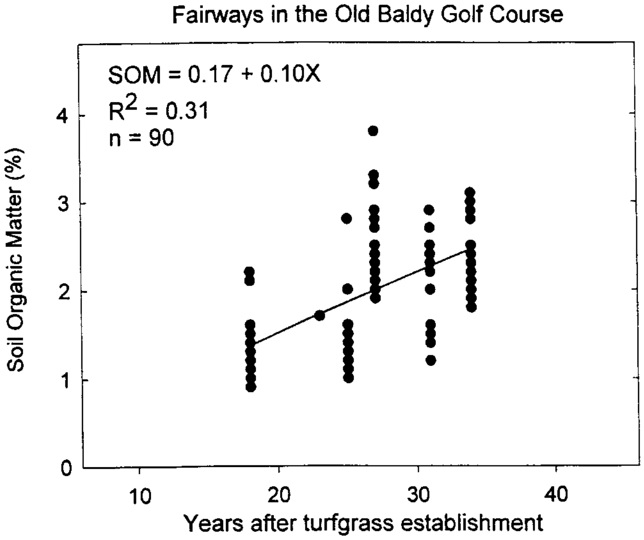

Fig. 3. Soil organic matter changes (to 15.2 cm) in fairways of the Old Baldy Golf Course, Wyoming.

Comparison of Soil Organic Matter on Fairways and Greens versus Tees

Complete data were collected on SOM in fairways, tees, and greens from Valley Country Club (age 31–45 yr), Boulder Country Club (age 31–35 yr), and Inverness Golf Course (age 24–26 yr). The analysis of variance indicated significant differences in SOM level in fairways, greens, and tees (Fig. 4). In both Boulder Country Club and Inverness Golf Course, the SOM ranking was fairways > green > tees. However, in Valley Country Club, the ranking of SOM was green = fairway > tees (Fig. 4). Differences in soil texture, grass type, management regimes, and traffic intensity may have contributed to the observed differences in SOM. Tees usually are capped with sand and suffer a higher degree of traffic and divot pressure, which may contribute to a low SOM. The more aggressive growth of creeping bentgrass used on putting greens may have contributed to the higher observed SOM for greens compared with tees where Kentucky bluegrass and perennial grass were used. The finer-textured soil in fairways also may have reduced the rate of decomposition, resulting in higher SOM for fairways than in tees and greens.

Relationships of Soil Organic Matter versus Soil Mineral Content, pH, and Nitrogen Application Rate

In Fairways

In addition to the change in SOM over time after turf establishment, stepwise regression analysis revealed that the level of SOM was influenced by soil pH in fairways (Table 3). Soil pH ranged from 6.5 to 8.3. When pH was >7.3, the level of SOM decreased as soil pH increased; when soil pH was <7.3, SOM level was not affected by pH. Soil K level was positively, whereas Na level was negatively, associated with SOM content. Unexpectedly, there was not a clear trend of increasing SOM with increasing N application rate (Table 3). An explanation is that N application rate is adjusted based on turf performance in many golf courses and current N application rate may not reflect historic application rate. Higby and Bell (1999) had demonstrated that SOM is higher from the fertilized golf course fairway than in adjacent unfertilized soil (1.61 vs. 1.03%). The relation-

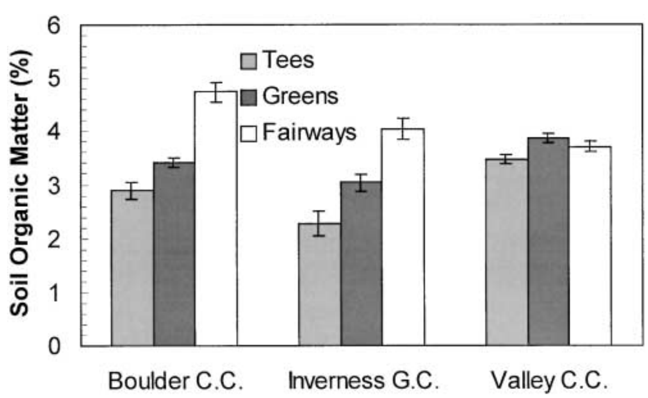

Fig. 4. The soil organic matter in greens, fairways, and tees of Boulder Country Club, Inverness Golf Course, and Valley Country Club. Turf in the tested sites was >25 yr old. Vertical lines represent standard errors.

ships between SOM and Mg, CEC, and Ca were not significant.

In Putting Greens

Stepwise analysis indicated that, in addition to the influence of years of turf growth on SOM content, SOM level was influenced by soil pH (Table 3). Soil pH for all soil samples in putting greens ranged from 5.9 to 8.0. When pH was >7.1, the level of SOM decreased as soil pH increased, but when soil pH was <7.1, SOM level was not affected by pH. The fitted model also included linear and quadratic CEC components, indicating CEC and SOM were closely associated. Furthermore, soil CEC was also highly correlated with soil Ca ($r = 0.98$), Mg ($r = 0.74$), Na ($r = 0.81$), and K ($r = 0.81$) content in putting greens.

CONCLUSIONS

Our results indicate that SOC sequestration in turf soils occurred at a significant rate, via input of organic C from roots and root and litter turnovers. However, our data do not provide information about changes that may have occurred in the initial phases of land transformation from native grassland or agricultural land to golf courses. The initial land use change involving land clearing, drainage, break of existing vegetation, replacement with perennial turfgrass, and nutrient subsidies in the form of fertilizers could have major impacts on C pools.

The rate increase in SOM was largely linear to about 30 yr for the putting greens and 25 yr for the fairways. The estimated rates of C sequestration from this study are about 1 t ha^{-1} yr^{-1}, and the area occupied by turfgrasses has been estimated to occupy about 20 million ha and is increasing. Years since turf establishment for the sites in this study is 21.1 + 13.8 yr (mean + standard deviation), with a median of 19 yr (Table 1). We assume that rates estimated here are representative of rates in other regions and other turf types, average ages since establishment, and standard deviations in age distribution under a normal distribution and that sequestration is occurring for either 25 or 30 yr (61 or 74% of the area under the normal curve, respectively). If such assumptions are correct, then C sequestration in soils within urban landscapes in the USA can be estimated to sequester 12 to 15 million t C yr^{-1} during 25 to 30 yr, an amount comparable to the 13 million t C yr^{-1} estimated to be sequestered by CRP lands in the USA (Follett et al., 2001). Thus, urban landscapes provide an important sink to help offset C emissions in the USA while also adding to the amounts of C sequestered annually in U.S. cropland, grazing land, and forest soils.

This report is, to the knowledge of the authors, one of the first to estimate the importance of urban landscapes to soil C sequestration. The data presented need to be compared with data collected in other regions and under various urban turf management and conditions. The processes whereby C is sequestered under turf need to be better understood, including the role of fertilization, clipping height, frequency of clipping, plant species, irrigation management, climate, and soil type and texture. In summary, these data indicate that turf is important in sequestering SOC and improving soil quality for long periods of time after establishment but that much additional research is needed.

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