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Effects of golf course management on subsurface soil properties in Iowa

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Abstract

Currently, in the USA and especially in the Midwest region, urban expansion is developing turfgrass landscapes surrounding commercial sites, homes, and recreational areas on soils that have been agriculturally managed for decades. Often, golf courses are at the forefront of conversations concerning anthropogenic environmental impacts since they account for some of the most intensively managed soils in the world. Iowa golf courses provide an ideal location to evaluate whether golf course management is affecting the quality of soils at depth. Our study evaluated how soil properties relating to soil health and resiliency varied with depth at golf courses across Iowa and interpreted relationships of these properties to current golf course management, previous landuse, and inherent soil properties. Systematic variation in soil properties including sand content, NO_3, and SOM were observed with depth at six Iowa golf courses among three landform regions. Variability in sand content was identified between the 20 and 50 cm depth classes at all courses, where sand content decreased by as much as 37%. Highest concentrations of SOM and NO_3 were found in the shallowest soils, whereas total C and P variability was not related to golf course management. Sand content and NO_3 were found to be directly related to golf course management, particularly at shallow depths. The effects of golf course management dissipated with depth and deeper soil variations were primarily due to natural geologic conditions.

1. Introduction

Critical evaluation of resilience and health of soil resources has been fueled by a recent urgency to understand anthropogenic impacts on environmental resources relating to local, regional, and international environmental sustainability and quality (Doran and Zeiss, 2000;Glanz, 1995). Urban expansion is a primary cause for these recent concerns. Currently, in the USA and especially in the Midwest region, urban expansion is developing turfgrass landscapes surrounding commercial sites, homes, and recreational areas on soils that have been agriculturally managed for decades (Qian and Follett, 2002). Often, golf courses are at the forefront of conversations concerning anthropogenic environmental impacts since they account for some of the most intensively managed soils in the world (Balogh and Walker, 1992).

Limited information is available documenting changes in soils due to golf course management, especially at depth, since most studies focus on the rooting depth of turfgrass and near the surface where soils are engineered to ideal texture classes (Bauters et al., 2000). Qian and Follett (2002) conducted a study on the effects of landuse change to turfgrass on soil organic matter (SOM) and found that previous landuse imparted a strong baseline control. However, while this study analyzed data from nearly 700 data sets, the results were limited to the top 15 cm of soil. In contrast, deep soil quality affects via landuse management has been observed in agricultural systems. Tomer and Burkart (2003) observed a significant increase in soil nutrient concentrations at a depth of 17 m below ground surface that was associated with historical fertilizer applications that occurred 20 years prior. Furthermore, they estimated NO_3-N percolation rates in loess soils to be approximately 0.67 m/yr. With the apparent decades-long translocation of soil nutrients after agricultural soil management, it is of interest to

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determine whether golf course management is similarly affecting the resiliency and long-term sustainability of soil resources.

There are over 400 golf courses in Iowa and many of these have been in operation for decades. With some of the most productive agricultural soils in the world, Iowa golf courses provide an ideal location to evaluate whether golf course management is affecting the quality of soils at depth. Specifically, our study objectives were to: 1) evaluate how soil physical and chemical properties relating to soil health and resiliency varied with depth at golf courses across Iowa; and 2) interpret relationships of these properties to current golf course management, previous landuse, and inherent soil properties.

2. Materials and methods

Our study sites consisted of 6 golf courses across Iowa, which were selected from approximately 421 golf courses in the state. A stratified random design was used to select courses by alphabetically grouping courses based on their location in eastern, central, and western Iowa and separating them into 18-hole and 9-hole classes. Courses were then selected using a random number generator. If permission for sampling was not obtained from the course, the next randomly selected course was selected. Ultimately, three 18-hole and three 9-hole courses were selected (Figure 1). Iowa is comprised of several landform regions that are associated with different glacial advances and post-glacial erosion (Prior, 1991), and courses were selected in a variety of landform regions. One course was located on the Iowan Surface landform region in Eastern Iowa which consists of a significantly dissected glacial landscape and loamy pedisediment. Two courses were located on the Southern Iowa Drift Plain, which is a highly weathered pre-Illinoian glacial landscape capped in loess. Finally, three courses were located on the Des Moines Lobe which consists of recent Wisconsinan age glacial deposits and hummocky topography (Table 1).

Three of the courses (Central 9, West 9, and West 18) were combined public and private use in towns of less than 5,000 people. The other three courses (East 9, East 18, and Central 18) were privately managed country clubs positioned in communities of 10-60,000 people. The smaller 9-hole courses ranged from 20 to 33 ha in size compared to the larger 18-hole courses which ranged from 37 to 68 ha. Tee boxes, greens, and fairways at the courses consisted of bentgrass except at the West 9 and Central 9 courses where fairways consisted of a variety of bentgrass, bluegrass, and rye. Grass varieties in roughs varied widely but consisted mainly of bentgrass, bluegrass, fescue, rye, and annual bluegrass in varying proportions. For each course, superintendents recorded and made available annual fertilizer application rates (typically four applications per year) for tee boxes, fairways, and roughs (Table 2). Generally, the roughs received the least fertilizer while the tee boxes received the most. Four out of six roughs received no fertilizer. Only one course (West 9) applied P fertilizer, whereas all courses applied N and K fertilizer. Prior land use at the courses was identified from historical air photography which was available starting in the 1930s (Iowa Department of Natural Resources, 2017). Golf course opening dates were verified with the superintendents (Table 1).

At each course, soil samples were collected in conjunction with shallow monitoring well installations being performed for a water quality study (Figure 2; Schilling and Streeter (2017)). Based on conversation with course superintendents, sampling locations were selected that could be easily accessed multiple times with minimal course disruption. Soil samples were collected according to the stratigraphy encountered at each site. Sampling depths were consistent within each course, but varied among courses based on the depth required to breach the water table for the water quality assessment (Table 1).

Continuous core was collected from each borehole by which the soil was described according to Schoeneberger (2012). Soil samples were collected, air dried and ground to pass a 2 mm sieve and lab analyzed according to Brown (1998) for P by strong Bray extraction. Furthermore, total soil carbon (TC) and total soil nitrogen (TN) were determined by elemental analysis via dry combustion and chromatography (Costech Analytical Technologies, 2015). Soil organic Matter (SOM) was determined by weight loss on ignition (Walkley and Black, 1934) as described by Schulte (1995). Nitrate nitrogen (NO_3) was measured by segmental flow analysis. Particle size distribution was determined by x-ray absorption (Micromeritics Instrument Corporation, 2015). A total of 127 soil samples were collected and analyzed (Table 1).

3. Results

Site stratigraphy was expectedly variable across the range of courses. The courses were located on varying landscape positions and soils formed in a variety of different parent materials including alluvium, glacial till, and loess. Depth of soil development ranged from 26 cm in glacial till at the central 18 course to 172 cm in loess at the west 18 course. Soils were less variable within courses, but variations were observed due to golf course management, primarily in terms of soil texture. In many locations, natural sand layers were identified at varying depths as well as evidence of human alteration to soil texture near the soil surface. On average, sand content was 25% higher in the upper 20 cm compared to the next lower depth class (50 cm depth) for all courses (Table 3 and Figure 3). Decreasing sand content with depth was most noticeable in courses on the Southern Iowa Drift Plain where average sand content decreased from 45 to 8%. However, since background sand content in soils from different geologic regions ranged widely among the courses (11-74%), we could not quantify the statistical significance of the sand content differences due to the limited sample size. In essence, testing for changes in sand content in courses could be done within the same landform region because soils have similar background conditions, but in our study we have only 1-3 courses per landform region.

In contrast to physical properties, varying concentrations of soil chemical properties were identified near the soil surface at multiple courses (Table 3). Course average TC and SOM ranged from 0.45-4.11% and 0.76-1.89%, respectively and ranged from 0.11-4.82% and 0.21-5.50% for individual samples. Likewise, SOM ranged from 2.9 to 5.5% in samples collected at 20 cm, and was weakly correlated to TC (r=0.27). SOM decreased with depth at all courses (r=0.47) regardless of landform region, whereas TC was not correlated to depth. Additional sampling is required to test the statistical significance of changes in soil chemical properties with depth. NO_3 and TN concentrations also decreased with increasing depth (r=0.41 and r=0.40, respectively). NO_3 concentrations were observed to decrease at the greatest rates between the first two depth classes (20 to 50 cm), whereas TN decreased more gradually. NO_3 concentrations decreased substantially from 15 to 2 mg/kg between 20 and 50 cm at East 18 located on the Iowan surface while concentrations dropped by more than 50% at all other locations by 100 cm. C/N ratio ranged from 13 at the East 9 course (floodplain) to 57 at the Central 18 course (glacial upland). C/N ratios of more than 20 generally occurred at depths greater than 20 cm. However, C/N ratios were not significantly correlated with depth. Mean P concentrations ranged from 18-67 mg/kg and were not correlated with any other soil property measured.

4. Discussion

4.1. Soil Physical Properties

In this study, we evaluated soil conditions at six randomly selected Iowa golf courses located in three different landform regions of the state. Despite inherent variation associated with parent materials, study results indicated systematic variation in several soil properties with depth at the Iowa golf course sites. These systematic variations by depth are intriguing, but require further study to expand sample sizes in order to test statistical significance. Even so, preliminary conclusions may be drawn regarding the significance of landuse on soil properties.

At a gross scale, soil particle size distributions were mainly associated with the parent material of the region. Typical sand contents of loess in western Iowa consist of less than 10% sand, whereas soils formed in glacial till in central Iowa often exceed 50% sand and may be highly variable (Soil Survey Staff, 2016). Our study found less than 10% sand in the unaltered soil formed in loess from 20-100 cm at the West 18 course. However, the surface soil horizon was much higher (45%) at this course. Unlike the deeper depth classes, the elevated sand content near the soil surface was not likely an inherent soil property due to the nature of the loess parent material, but rather caused by golf course landuse. Our study found sand content was much higher at the four courses located on glacial till derived soils (West 9, Central 9 and 18, and East 18) compared to the courses located on loess (West 18) or alluvium (East 9) (Table 4). With the exception of the Central 9 course, the glacial derived soils exhibited a sharp decrease in sand content between the 20 and 50 cm depths (as much as 37%) that may not be explained primarily by inherent soil properties. Although natural variability in sand content varied widely between landform regions, average sand content for all courses was 25% higher in the 0-20 cm interval compared to the 20 to 50 cm depth.

Golf course soils are regularly aerated and top-dressed by adding new sand to the surface of the established soil profile (Bandaranayake et al., 2003;Bauters et al., 2000). Golf course superintendents at our study sites confirmed that topdressing was performed on an annual basis at all but the Central 9 course. This topdressing management approach explains the elevated sand content near the surface at our study sites. Increased sand content of the surface soil horizons due to topdressing may have several implications for soil health and development. Altering the particle size distribution of the soil may in-turn alter several soil properties including bulk density and porosity (Arya and Paris, 1981;Gupta and Larson, 1979), soil compaction (Bodman and Constantin, 1965), hydraulic conductivity and water holding capacity (Campbell and Shiozawa, 1992;Jabro, 1992), as well as SOM content and distribution (Anderson et al., 1981;Puget et al., 2000;Tiessen and Stewart, 1983), and NO_3 concentrations via CEC (Anderson et al., 1981;Arya and Paris, 1981;Ersahin et al., 2006). Bandaranayake et al. (2003) explained that topdressing soil with sand prolongs the time required for SOM content to reach equilibrium in the soil profile. Since SOM affects several other soil properties, it is likely that the soil conditions at our study sites are much less stable than those at surrounding non-golf course sites.

4.2. Soil chemical properties

Similar to the inherent nature of soil texture, TC content may also be primarily dependent on the soil parent material and may be highly spatially variable (Huang et al., 2007).

Courses on unaltered glacial deposits (West 9, Central 9 and 18) exceeded 4% TC due to high inorganic carbon concentrations, whereas courses on reworked Iowan Surface glacial sediments (East 18) as well as weathered Southern Iowa Drift Plain deposits had TC concentrations less than 2%. These reworked and weathered soils have likely experienced inorganic carbon leaching which has left the soils void of almost all inorganic carbon. This was quite noticeable when comparing TC between landform regions at all depths and it also explains the variability in C/N ratio at depths greater than 100 cm in our study where C/N ratio is 4 to 10 times greater in Des Moines Lobe soils. The variability in TC (and C/N ratio below 100 cm) that we have identified through this study may be entirely affected by parent material and natural weathering patterns.

Soil chemical properties including SOM at the Iowa golf course were altered from their long-term equilibrium conditions established under native perennial vegetation in response to modern agricultural management and urban landuse. For example, agricultural drainage in conjunction with row crop agriculture can decrease SOM between 24 and 89% compared to that of perennially managed soils (Knops and Tilman, 2000;Kucharik et al., 2001;VandenBygaart et al., 2003). In urban areas, Qian and Follett (2002) conducted a study on the effects of landuse change to turfgrass and found that previous landuse imparted a strong baseline control on SOM concentrations. Bandaranayake et al. (2003) estimated that turfgrass systems (e.g. golf courses) could sequester up to 32 Mg/ha of soil organic carbon (approximately 64Mg/ha of SOM) in the top 20 cm of soil within 30 years of establishment. At the Iowa golf courses, we observed substantially lower SOM contents in the upper 20 cm (2.9 to 5.5%) in samples collected at 20 cm but concentrations were highest in the uppermost layer and decreased with depth at all courses. Although accumulation of SOM in the upper 20 cm is consistent with Bandaranayake et al. (2003), attributing specific SOM changes to golf course management is not possible with our study. The SOM profiles could define native perennial, agricultural, or urban turfgrass landuse.

In agricultural systems, application of N fertilizer has been found to migrate through the soil profile (De Haan et al., 2017;Tomer and Burkart, 2003). In deep loess soils of western Iowa, Tomer and Burkart (2003) documented a zone of high soil NO_3 located 17 m below land surface due to over-application of commercial fertilizer 20 years earlier. De Haan et al. (2017) observed that cropping systems has a large impact on residual soil NO_3 in the upper 1.8 m of the soil profile. Residual soil NO_3 in the soil profile under continuous corn with a rye cover crop was more than seven times higher than a perennial grass system. Others have similarly observed residual NO_3 concentrations under agricultural land use in Iowa as high as 60 mg/kg (Blackmer et al., 1989). However, the golf courses in our study applied varying rates of slow release N fertilizer to Tee boxes and fairways, and only two courses (East 9 and 18) applied N fertilizer to the roughs (Table 2). We estimated (based on typical bulk density values for surface soils in Iowa) that soil NO_3 concentrations ranged from 15-35 kg/ha for our study sites. Our study shows evidence of higher NO_3 levels in golf course soils than that of typical perennially managed soils (less than 10 kg/ha), but not necessarily as high as typical agricultural management (40-70 kg/ha) (De Haan et al., 2017). Recent studies provide evidence that once application of N fertilizer ceases, the top 1 m of the soil may return to native concentrations of NO_3 within 10 years (Streeter and Schilling, 2017). Since the courses for our study have been established for over 50 years, it is likely that the current NO_3 concentrations near the soil surface reflects golf course management rather than historical agricultural practices.

P concentrations at the courses were not correlated with any other soil property measured during our study. Furthermore, P fertilizer was only applied at 1 course (West 9) on the rough. Typically, background P concentrations in Iowa soils vary from 0-100 mg/kg depending on the mineralogy of the soil parent material (Fenton, 1999). Loess derived soils generally have the highest P, while glacial till derived soils will have some of the lowest P concentrations (Fenton, 1999). Similarly, our study identified the highest P concentrations at the West 18 course (loess derived soil) and the lowest P concentrations at the Central 18 course (glacial till derived soil). Our study results suggest no significant alterations to background soil P concentrations by golf course management.

5. Conclusions

In this study, systematic variation in soil properties including sand content, NO_3, and SOM were observed with depth at six Iowa golf courses among three landform regions. Variability in sand content was identified between the 20 and 50 cm depth classes at all courses, where sand content decreased by as much as 37%. Highest concentrations of SOM and NO_3 were found in the shallowest soils, whereas TC and P variability was not related to golf course management and did not correlate with depth. Although many of the soil properties measured for this study may be influenced by parent material and native vegetation, sand content and NO_3 were found to be directly related to golf course management, particularly at shallow depths. The effects of golf course management dissipated with depth and deeper soil variations were primarily due to natural geologic conditions. Further work is recommended to

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increase sample size of course sites within different landform regions to better quantify the variability of soil properties with depth. Likewise, additional investigation of spatial patterns within individual courses would improve characterization of soil quality patterns among managed and unmanaged areas. Despite limitations, our study indicates that golf course management is affecting the surface and subsurface quality of soils.

References

Anderson, D., Saggar, S., Bettany, J., and Stewart, J.: Particle size fractions and their use in studies of soil organic matter: I. The nature and distribution of forms of carbon, nitrogen, and sulfur, Soil Science Society of America Journal, 45, 767-772, 1981.

Arya, L. M., and Paris, J. F.: A physicoempirical model to predict the soil moisture characteristic from particle-size distribution and bulk density data, Soil Science Society of America Journal, 45, 1023-1030, 1981.

Balogh, J. C., and Walker, W. J.: Golf course management & construction: Environmental issues, CRC Press, 1992.

Bandaranayake, W., Qian, Y., Parton, W., Ojima, D., and Follett, R.: Estimation of soil organic carbon changes in turfgrass systems using the CENTURY model, Agronomy Journal, 95, 558-563, 2003.

Bauters, T., Steenhuis, T., DiCarlo, D., Nieber, J., Dekker, L., Ritsema, C., Parlange, J.-Y., and Haverkamp, R.: Physics of water repellent soils, Journal of Hydrology, 231, 233-243, 2000.

Blackmer, A., Pottker, D., Cerrato, M., and Webb, J.: Correlations between soil nitrate concentrations in late spring and corn yields in Iowa, Journal of Production Agriculture, 2, 103-109, 1989.

Bodman, G., and Constantin, G.: Influence of particle size distribution in soil compaction, California Agriculture, 36, 567-591, 1965.

Brown, J. R.: Recommended chemical soil test procedures for the North Central Region, Missouri Agricultural Experiment Station, University of Missouri--Columbia, 1998.

Campbell, G., and Shiozawa, S.: Prediction of hydraulic properties of soils using particle-size distribution and bulk density data, Indirect methods for estimating the hydraulic properties of unsaturated soils. University of California, Riverside, 317-328, 1992.

De Haan, R. L., Schuiteman, M. A., and Vos, R. J.: Residual soil nitrate content and profitability of five cropping systems in northwest Iowa, PloS one, 12, e0171994, 2017.

Doran, J. W., and Zeiss, M. R.: Soil health and sustainability: managing the biotic component of soil quality, Applied soil ecology, 15, 3-11, 2000.

Ersahin, S., Gunal, H., Kutlu, T., Yetgin, B., and Coban, S.: Estimating specific surface area and cation exchange capacity in soils using fractal dimension of particle-size distribution, Geoderma, 136, 588-597, 2006.

Fenton, T.: Phosphorus in Iowa soils, Agronomy Department, Iowa State University, 1999.

Glanz, J.: Saving our soil: solutions for sustaining earth's vital resource, Johnson Books, 1995.

Gupta, S., and Larson, W.: Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density, Water resources research, 15, 1633-1635, 1979.

Huang, X., Senthilkumar, S., Kravchenko, A., Thelen, K., and Qi, J.: Total carbon mapping in glacial till soils using near-infrared spectroscopy, Landsat imagery and topographical information, Geoderma, 141, 34-42, 2007.

Natural Resources Geographic Information Systems Library: https://programs.iowadnr.gov/nrgislibx/, access: April, 2017.

Jabro, J.: Estimation of saturated hydraulic conductivity of soils from particle size distribution and bulk density data, Transactions of the ASAE, 35, 557-560, 1992.

Knops, J. M., and Tilman, D.: Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment, Ecology, 81, 88-98, 2000.

Kucharik, C. J., Brye, K. R., Norman, J. M., Foley, J. A., Gower, S. T., and Bundy, L. G.: Measurements and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: potential for SOC sequestration during the next 50 years, Ecosystems, 4, 237-258, 2001.

Prior, J. C.: Landforms of Iowa, University of Iowa Press, 1991.

Puget, P., Chenu, C., and Balesdent, J.: Dynamics of soil organic matter associated with particle-size fractions of water-stable aggregates, European Journal of Soil Science, 51, 595-605, 2000.

Qian, Y., and Follett, R. F.: Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data, Agronomy Journal, 94, 930-935, 2002.

Schilling, K. E., and Streeter, M. T.: Groundwater Nutrient Concentrations and Mass Loading Rates at Iowa Golf Courses, JAWRA Journal of the American Water Resources Association, 2017.

Schoeneberger, P. J., Wysocki, D.A., Benham, E.C., Soil Survey Staff.: Field Book for Describing and Sampling Soils, Version 3. 0, Government Printing Office, 2012.

Schulte, E.: Recommended soil organic matter tests, Recommended Soil Testing Procedures for the North Eastern USA. Northeastern Regional Publication, 52-60, 1995.

Web Soil Survey: http://websoilsurvey.nrcs.usda.gov, access: December, 2016.

Streeter, M. T., and Schilling, K. E.: Soil Properties in Native, Reconstructed, and Farmed Prairie Potholes: A Chronosequence Study of Restoration Timeframes, Ecological Restoration, 35, 6-12, 2017.

Tiessen, H., and Stewart, J.: Particle-size fractions and their use in studies of soil organic matter: II. Cultivation effects on organic matter composition in size fractions, Soil Science Society of America Journal, 47, 509-514, 1983.

Tomer, M., and Burkart, M.: Long-term effects of nitrogen fertilizer use on ground water nitrate in two small watersheds, Journal of Environmental Quality, 32, 2158-2171, 2003.

VandenBygaart, A., Gregorich, E., and Angers, D.: Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies, Canadian Journal of Soil Science, 83, 363-380, 2003.

Walkley, A., and Black, I. A.: An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method, Soil science, 37, 29-38, 1934.

Figure Captions:

Figure 1. Location map showing the six golf courses chosen for this study.

Figure 2. Soil sampling and monitoring well installation at East 18 course.

Figure 3. Profile of selected soil constituents with depth at the six Iowa golf courses.

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Table 1. Golf course site information.

Course	Year Opened	Previous Landuse	Landform	Parent Material	Max. Depth (cm)	Number of Samples
West 18	1963	row crop	Southern Iowa Drift Plain	loess	767	19
West 9	1938	row crop	Des Moines Lobe	glacial till	380	20
Central 9	1965	row crop	Des Moines Lobe	glacial till	457	18
Central 18	1915	no prior history	Des Moines Lobe	glacial till	506	26
East 18	1965	row crop	Iowan Surface	glacial sediments	546	22
East 9	1920	no prior history	Southern Iowa Drift Plain	alluvium	405	22

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Table 2. Summary of annual fertilizer rates at selected Iowa golf courses.

Course	Position	N kg/ha	Weighted Course Average N kg/ha	P kg/ha	K kg/ha
West 18	Tee	90		0	44
West 18	Rough	0		0	0
West 18	Fairway	77	28.5	0	11
West 9	Tee	73		5.4	22
West 9	Rough	0		0	0
West 9	Fairway	37	15.4	0	6
Central 18	Tee	146		0	26
Central 18	Rough	0		0	0
Central 18	Fairway	110	41.7	0	0
Central 9	Tee	51		0	17
Central 9	Rough	0		0	0
Central 9	Fairway	51	18.5	0	17
East 18	Tee	87		0	132
East 18	Rough	112		0	17
East 18	Fairway	63	95.8	0	107
East 9	Tee	169		0	20
East 9	Rough	22		0	7
East 9	Fairway	115	59.2	0	19

Table 3. Soil conditions by depth at Iowa golf courses.

Course	**n**	**Depth Class**	**Sand %**	**P mg/kg**	**SOM %**	**NO3 mg/kg**	**TC %**	**TN %**	**C/N**
Central 18	2	20	53 +/-42	18 +/-2	5.50 +/-4.24	5.00 +/-2.82	4.63 +/-0.17	0.33 +/-0.28	22 +/-19
Central 18	5	50	40 +/-23	18 +/-9	4.46 +/-3.69	8.20 +/-6.22	4.82 +/-2.35	0.29 +/-0.21	47 +/-75
Central 18	6	100	40 +/-21	03 +/-3	1.65 +/-1.83	3.83 +/-2.31	3.08 +/-2.18	0.10 +/-0.08	30 +/-33
Central 18	12	500	26 +/-25	02 +/-2	0.48 +/-0.27	1.25 +/-0.45	4.21 +/-2.14	0.05 +/-0.05	84 +/-37
Central 18	1	1000	05 +/-	02 +/-	0.30 +/-	1.00 +/-	4.69 +/-	0.07 +/-	67 +/-
Central 9	2	20	35 +/-2	14 +/-1	5.50 +/-0.14	15.50 +/-	2.58 +/-0.48	0.18 +/-0.07	14 +/-4
Central 9	2	50	50 +/-1	10 +/-0	2.35 +/-1.76	4.00 +/-4.24	1.81 +/-0.43	0.08 +/-0.01	22 +/-12
Central 9	5	100	46 +/-10	04 +/-9	1.52 +/-1.13	1.60 +/-0.89	1.15 +/-0.84	0.06 +/-0.05	19 +/-1
Central 9	9	500	61 +/-10	04 +/-3	0.48 +/-0.30	1.11 +/-0.33	1.51 +/-1.25	0.01 +/-0.02	15 +/-5
East 18	1	20	81 +/-	31 +/-	2.60 +/-	15.00 +/-	1.54 +/-	0.11 +/-	14 +/-
East 18	6	50	74 +/-9	27 +/-1	1.53 +/-0.95	2.83 +/-2.31	0.77 +/-0.54	0.04 +/-0.03	19 +/-6
East 18	4	100	78 +/-8	17 +/-1	0.40 +/-0.21	1.25 +/-0.50	0.18 +/-0.12	0.01 +/-0.00	18 +/-9
East 18	9	500	79 +/-25	15 +/-3	0.21 +/-0.16	1.11 +/-0.33	0.11 +/-0.08		
East 18	2	1000	42 +/-0	02 +/-2	0.80 +/-0	1.00 +/-0	1.04 +/-0.10		
East 9	4	20	11 +/-5	16 +/-1	3.15 +/-1.96	4.50 +/-3.31	1.74 +/-1.77	0.10 +/-1.12	17 +/-22
East 9	6	50	07 +/-2	23 +/-5	1.48 +/-0.42	1.00 +/-0	0.94 +/-0.36	0.09 +/-0.02	10 +/-2
East 9	12	500	28 +/-33	27 +/-2	0.57 +/-0.26	1.00 +/-0	0.22 +/-0.08	0.02 +/-0.02	11 +/-1
West 18	1	20	45 +/-	97 +/-	2.90 +/-	9.00 +/-	1.72 +/-	0.14 +/-	12 +/-
West 18	6	50	06 +/-11	28 +/-4	2.92 +/-0.95	5.83 +/-3.43	0.90 +/-0.75	0.04 +/-0.05	22 +/-22
West 18	3	100	01 +/-0	46 +/-2	2.20 +/-0.85	3.67 +/-2.08	1.07 +/-0.58	0.08 +/-0.01	13 +/-5
West 18	6	500	16 +/-36	98 +/-3	0.63 +/-0.35	1.17 +/-0.40	0.24 +/-0.12	0.01 +/-0.01	31 +/-36
West 18	3	1000	10 +/-6	48 +/-3	0.67 +/-0.11	1.00 +/-0	0.20 +/-0.05	0.01 +/-0.01	20 +/-
West 9	1	20	26 +/-	19 +/-	2.90 +/-	3.00 +/-	3.12 +/-	0.12 +/-	26 +/-
West 9	3	50	17 +/-4	28 +/-9	4.97 +/-1.54	5.33 +/-2.08	3.04 +/-0.84	0.2 +/-0.07	15 +/-4
West 9	5	100	33 +/-15	21 +/-2	1.56 +/-0.92	3.60 +/-2.61	2.27 +/-0.84	3.6 +/-0.05	23 +/-9
West 9	11	500	33 +/-24	38 +/-4	0.76 +/-0.56	1.27 +/-0.64	1.87 +/-0.86	0.02 +/-0.03	19 +/-16

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Table 4. Mean soil conditions at Iowa golf courses.

Course	Sand %	P mg/kg	SOM %	NO3 mg/kg	TC %	TN %	C/N
Central 18	33 +/-25	18 +/-25	1.89 +/-2.65	3.46 +/-3.87	4.11 +/-2.06	0.13 +/-0.15	57 +/-48
Central 9	52 +/-12	50 +/-26	1.53 +/-1.74	3.16 +/-5.54	1.56 +/-1.05	0.04 +/-0.06	18 +/-6
East 18	74 +/-19	37 +/-24	0.76 +/-0.84	2.22 +/-3.17	0.45 +/-0.50	0.01 +/-0.03	22 +/-7
East 9	19 +/-26	57 +/-22	1.29 +/-1.26	1.63 +/-1.86	0.69 +/-0.91	0.05 +/-0.06	13 +/-13
West 18	11 +/-22	67 +/-44	1.72 +/-1.24	3.42 +/-3.18	0.64 +/-0.63	0.03 +/-0.04	23 +/-22
West 9	30 +/-20	31 +/-35	1.7 +/-1.69	2.55 +/-2.13	2.20 +/-0.91	0.06 +/-0.07	20 +/-10

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403 Figure 1.

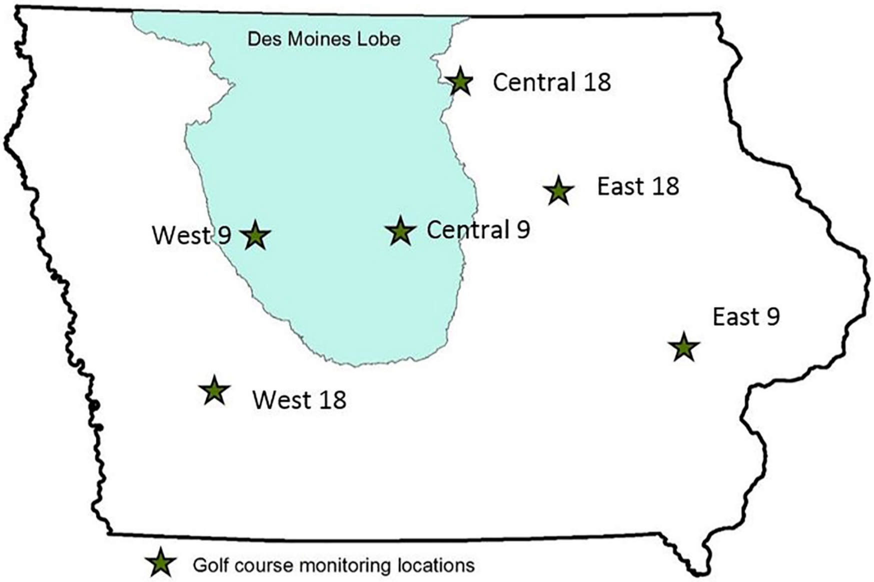

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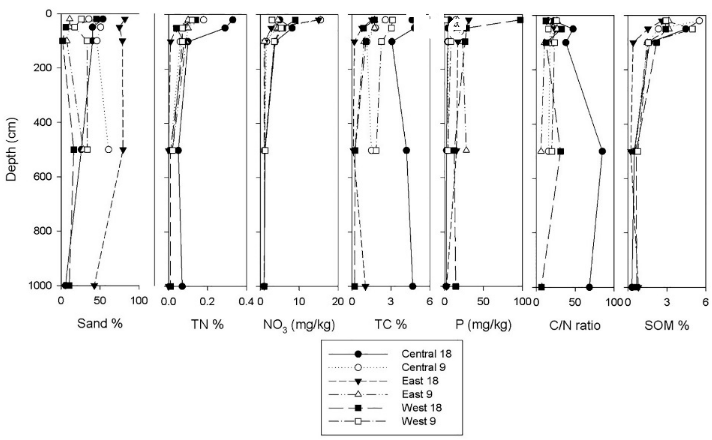
Figure 2.

SOIL Discuss., https://doi.org/10.5194/soil-2017-29
Manuscript under review for journal SOIL
Discussion started: 2 January 2018

409 Figure 3.



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