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High and Low Management Input Regimes Result in Similar Net Carbon Sequestration Rates in Zoysiagrass Golf Course Fairway Turf

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Summary
This study was conducted from 2013–2016 to determine how irrigation and N fertilization may be managed to enhance carbon (C) sequestration in turf. In this study, the annual rate of change in soil organic carbon (ΔSOC) was measured under two management regimes, a high management input regime (HMI) and low management input regime (LMI), in a 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) golf course fairway. Both management regimes maintained acceptable turf quality and at least 75% green cover during both summers. In both management regimes, soil organic carbon (SOC) increased after the 3.16-yr (1154-d) period indicating that C was sequestered in the soil. The C emissions from turfgrass maintenance practices (mowing, irrigation, and fertilization and pesticide applications) are known as "hidden carbon costs" (HCC). The average gross C sequestration rates for the two treatments were not statistically different at 1046 kg C/ha/yr and 976 kg C/ha/yr in HMI and LMI, respectively, prior to subtracting HCC. Once the total estimated HCC was included, the average net sequestration rate was 412 kg C/ha/yr and 616 kg C/ha/yr in HMI and LMI, respectively, with no statistical differences. Our study indicates high and low management input regimes result in similar net C sequestration rates in zoysiagrass golf course fairway turf.

Rationale
Carbon dioxide (CO_2) is an important greenhouse gas (GHG) implicated in global climate change. Turfgrass covers an estimated 12.8 to 20 million ha in the United States and has the capacity to sequester or emit significant amounts of CO_2 from/into the atmosphere via photosynthesis and respiration. Further research is needed

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to evaluate and develop turf management practices, including N fertilization and irrigation regimes, to help both sequester C and minimize C emissions.

Objective

The objective of this study was to quantify the soil organic carbon (SOC) sequestration rate in zoysiagrass fairway turf and determine how hidden carbon costs (HCC) of maintenance practices (irrigation and N fertilization) may be managed to enhance C sequestration.

Study Description

This field study was conducted under an automated rainout shelter at the Rocky Ford Turfgrass Research Center, Manhattan, KS, from August 22, 2013 to October 19, 2016 (Figure 1). By shielding turfgrass from rainfall, researchers can control the amount of water applied to plots (Figure 2). The soil was a Chase silty clay loam with a pH of 7.0. 'Meyer' zoysiagrass was sodded June 4, 2013, and maintained at a 1-inch mowing height. Two management regimes, replicated four times each, were assigned to plots in a randomized complete-block design. The two management regimes included: (i) urea (98 kg N/ha/yr) + medium irrigation [66% reference evapotranspiration (ET_o) replacement], designated as high management input regime (HMI); and (ii) unfertilized (receiving no N fertilizer) + low irrigation (33% ET_o replacement), designated as low management input regime (LMI). The annual rate of change in soil organic carbon (SOC) (ΔSOC; kg C/ha/yr), which was the gross C sequestration rate, was calculated from the difference between 2013 and 2016 soil samples from a 0–12 inch depth and averaged over the 3.16-yr (1154-d) period (Figure 3). Energy expenditures in carbon equivalents (CE) known as HCC from turfgrass maintenance practices (irrigation, mowing, and fertilizer and pesticide applications) along with nitrous oxide (N_2O) emissions were measured and calculated for each plot within each management regime over the entire 3-yr study (Figure 4). These HCC (kg CE/ha/yr) were then subtracted from the gross C sequestration rates to determine net soil C sequestration rates for each management regime. In addition, the green turfgrass cover of each plot was measured by digital images during the growing season to evaluate turfgrass performance.

Results

At the end of the study, there were no differences in the ΔSOC between the management regimes within each soil depth (data not shown) or between management regimes averaged across all depths (0–12 inch) (Table 1). However, SOC increased significantly after the 1154-day period for both HMI and LMI, and C/N increased by 66% for HMI (Table 1), indicating that C was sequestered in the soil. During the 3-yr study, the zoysiagrass turf had an average gross C sequestration rate of 1010 kg C/ha/yr when averaged across both management input regimes and all three depths. Prior to subtracting HCC, average gross carbon C sequestration rates were not statistically different at 1046 kg C/ha/yr and 976 kg C/ha/yr in HMI and LMI, respec-

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tively (Tables 1 and 2). Once total estimated HCC was included, the average net sequestration rate was 412 kg C/ha/yr and 616 kg C/ha/yr in HMI and LMI, respectively, with no statistical differences (Table 2). In 2015 and 2016, HMI generally had more green turfgrass cover than LMI due to N fertilization and greater irrigation amounts (data not shown). However, the HMI's higher green turfgrass cover led to significantly more mowing events and greater HCC emissions in the HMI than the LMI (Table 2). Overall, both management input regimes remained higher than 75% green cover throughout both summers, including unfertilized zoysiagrass receiving only 33% ET_o twice a week with all rainfall excluded for 92 days during the summer. Our results indicate that under the conditions of this study, a higher-input management regime will not increase net C sequestration compared with a low management input regime in zoysiagrass golf course fairway turf.

The full manuscript for this experiment on C sequestration is available in *Agrosystems, Geosciences and Environment* (Braun and Bremer, 2019). This experiment was conducted in conjunction with another study on the same research plots, in which nitrous oxide emissions were measured (available in *Crop Science*, Braun and Bremer, 2018).

References

Braun, R.C., and D.J. Bremer. 2018. Nitrous oxide emissions from turfgrass receiving different irrigation amounts and nitrogen fertilizer forms. *Crop Sci*. 58:1762–1775. doi:10.2135/cropsci2017.11.0688

Braun, R.C. and D.J. Bremer. 2019. Carbon sequestration in zoysiagrass turf under different irrigation and fertilization management regimes. Agrosyst. Geosci. Environ. 2:180060. doi:10.2134/age2018.12.0060

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Table 1. Soil organic carbon (SOC) and soil carbon/nitrogen ratio (C/N) at the beginning (2013) and end of the study (2016), and average annual change in soil organic carbon (ΔSOC) across all depths (0–12 inch) and within each management regime

Management regime	n	SOC (kg C/ha)		C/N		ΔSOC (kg C/ha/yr)
		2013	2016	2013	2016	
High	12	17900 b[†]	21300 a	10.2 b	16.9 a	1046
Low	12	19100 b	22300 a	10.1	12.9	976

[†]Within a row, within each category, means with different lowercase letters are significantly different according to $\alpha_{bon} = 0.025$.

Table 2. The calculated gross and net soil organic carbon (SOC) sequestration rates using estimates of annual hidden carbon costs (HCC) of measured turf maintenance practices and measured annual nitrous oxide (N_2O) emissions in terms of carbon equivalents (CE) in a zoysiagrass fairway

	High management regime	Low management regime
Gross SOC sequestration rate (kg C/ha/yr)	1046 a[†]	976 a
Hidden carbon costs		
Nitrous oxide emissions HCC (kg CE/ha/yr)[‡]	351 a	254 b
Mowing HCC (kg CE/ha/yr)[§]	87 a	49 b
Irrigation HCC (kg CE/ha/yr)[§]	42 a	30 b
Fertilizer HCC (kg CE/ha/yr)[§]	127[¶]	0
Pesticide HCC (kg CE/ha/yr)[§]	27	27
Total HCC (kg CE/ha/yr)[#]	634 a	360 b
Net SOC sequestration rate (kg C/ha/yr)[††]	412 a	616 a

[†]Within a row, means with different lowercase letter are significantly different according to Fisher's Protected LSD ($P \leq 0.0001$).
[‡]Nitrous oxide emissions were converted from kg N_2O/ha/yr to kg CE/ha/yr.
[§]Mowing emissions were calculated using the number of cumulative annual mowing events of each plot multiplied by mower emissions, irrigation emissions were calculated from the total irrigation run time (hours) of each plot, and fertilizer and pesticide emissions were calculated based on conversion factors that take into account production, packaging, storage, and distribution requirements for fertilizer and pesticide active ingredient.
[¶]Within a row, means with no lowercase letter present did not have statistical analysis conducted.
[#]Total hidden carbon costs (HCC) for each plot were calculated as the sum of carbon equivalents from emissions of nitrous oxide, mowing, irrigation, fertilizer, and pesticide.
[††]Net sequestration rate = (gross SOC sequestration rate - total HCC).

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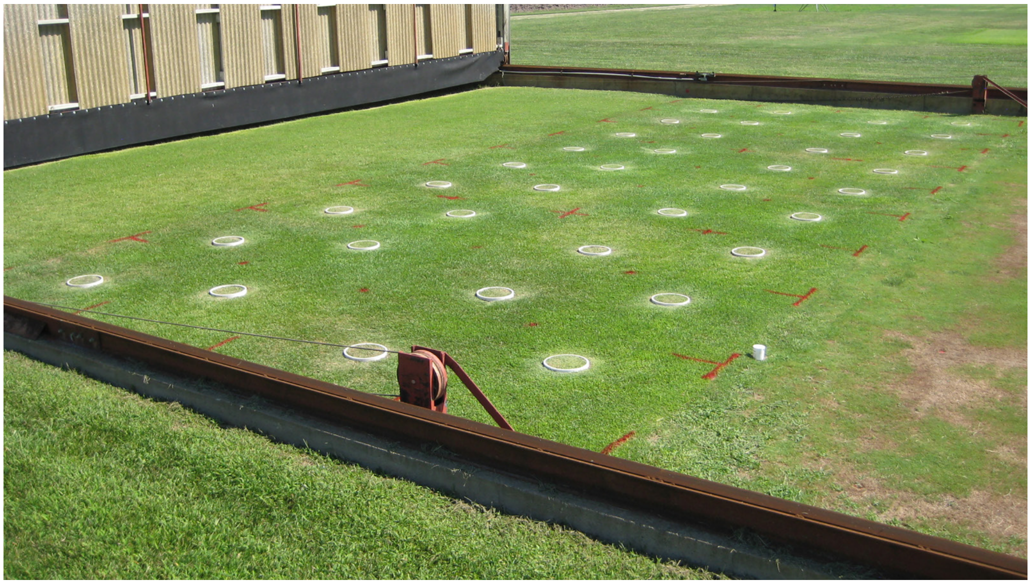

Figure 1. Automated rainout shelter that is activated by 0.01 inch of rain.

Figure 2. Plots received precise irrigation amounts based on daily reference evapotranspiration during the summer period.

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Figure 3. Soil measurements from 0 to 12 inch soil depth in each plot were obtained at study initiation (August 22, 2013) and again after the 3.16-yr (1154-d) study period on October 19, 2016.

Figure 4. Plots were managed the same as a zoysiagrass golf course fairway in the transition zone.

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