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

SPECIFIC MANAGEMENT PRACTICES CAN REDUCE GREENHOUSE GAS EMISSIONS

AND PROMOTE CARBON SEQUESTRATION IN GOLF COURSE FAIRWAYS

BY ROSS C. BRAUN, PH.D., PURDUE UNIVERSITY &
DALE J. BREMMER, PH.D., KANSAS STATE UNIVERSITY

Summary Points

1. Turfgrass soils have the potential to sequester carbon and emit nitrous oxide (N2O), both greenhouse gases.
2. Our results indicate high and low turf-management-input regimes result in similar net carbon sequestration rates in zoysiagrass golf course fairway turf, which had an average gross carbon sequestration rate of 902 pounds per acre per year.
3. The use of a controlled-release fertilizer, such as polymer-coated urea, instead of a urea, and/or less irrigation, will reduce N2O emissions in turfgrass.
4. Golf course superintendents can utilize less irrigation and controlled-release nitrogen fertilizers to promote environmental stewardship by conserving water and reducing N2O emissions while still promoting sequestration of atmospheric carbon.

5. In addition to a reduction in N_2O emissions and promoting carbon sequestration, these management practices can result in labor-saving benefits such as reductions in mowing requirements and fertilizer applications.

Turfgrass covers an estimated 6.33 million acres of golf-course managed areas worldwide (Barlett and James, 2011). Past research has shown that turfgrass soils have the ability to sequester atmospheric carbon (C) in the soil similar to other grassland soils, but little research has been conducted to document specific effects of turfgrass management practices – i.e., irrigation and fertilization – on carbon sequestration. Carbon sequestration occurs when more carbon dioxide (CO_2) – a greenhouse gas (GHG) – is removed from the atmosphere via photosynthesis of the plant than is returned to the atmosphere via respiration. Another GHG is nitrous oxide (N_2O), which is reported to be 310 times more effective at trapping longwave radiation in the atmosphere than CO_2 (IPCC, 2007). Nitrous oxide is a natural and human-produced byproduct, especially from agricultural activities such as nitrogen fertilization of agricultural (Mosier et al., 1998) and turfgrass (Bremer, 2006; Braun and Bremer, 2018b) systems. Due to the importance of these greenhouse gases to climate science and the acreage of golf course turf areas, USGA-funded research projects at Kansas State University were conducted to evaluate and develop turf management practices, including nitrogen fertilization and irrigation regimes, that sequestered atmospheric carbon and minimized N_2O emissions.

Method

Two field experiments were simultaneously conducted under an automated rainout shelter at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas, from 2013-2016 to determine how irrigation and nitrogen fertilization may be managed to enhance carbon sequestration and reduce N_2O emissions in turf (Braun and Bremer, 2018a; Braun and Bremer, 2019). Both experiments were conducted on 'Meyer' zoysiagrass (Zoysia japonica Steud.) maintained as a golf course fairway.

In experiment 1, the annual rate of change in soil organic carbon (SOC) – measured in kilograms of carbon per hectare per year (ΔSOC; kg C ha^{-1} yr^{-1}) – was measured under two turf management regime treatments.

Experiment 1 Treatments

- High-management-input regime (HMI): Irrigation replacement level of 66% reference evapotranspiration (ETo) + included urea applied at 98 kg N ha^{-1} yr^{-1} (2 pounds of nitrogen per 1,000 square feet per year)
- Low-management-input regime (LMI): Irrigation replacement level of 33% ETo + unfertilized turf

During June through August of 2014, 2015, and 2016, the two irrigation treatments were applied by hand watering individual plots twice a week using calculated amounts based on daily ETo rates from an on-site weather station. From September through May, when the rainout shelter was not activated, all plots received adequate irrigation that was less than or equal to one-half inch of water per week and any occurring precipitation. The annual rate of change in soil organic carbon – which was the gross carbon 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-year (1,154-day) period. Energy expenditures in carbon equivalents (CE) known as "hidden carbon costs" (HCC) from turfgrass maintenance practices – i.e., irrigation, mowing, fertilizer and pesticide applications – along with CE and HCC from N2O emissions, were measured and calculated for each plot within each management regime over the entire three-year study. These HCC (kg CE ha-1 yr-1) were then subtracted from the gross carbon sequestration rates to determine net soil carbon sequestration rates for each management regime. Additional data collected included percent green turf cover of plots using digital image analysis.

In experiment 2, N2O emissions were measured in zoysiagrass receiving two irrigation treatments and three nitrogen fertilization treatments.

Experiment 2 Treatments

- Two Irrigation Treatments
  - Irrigation replacement rate of 66% ETo
  - Irrigation replacement rate of 33% ETo
- Nitrogen Fertilization Treatments
  - Urea (46-0-0) applied at total of 98 kg N ha-1 yr-1 (2 pounds of nitrogen per 1,000 square feet per year)
  - Polymer-coated urea (PCU) (41-0-0; 90-day release) applied at total of 98 kg N ha-1 yr-1 (2 pounds of nitrogen per 1,000 square feet per year)
  - Unfertilized "control" (UF) receiving no nitrogen fertilizer

Irrigation treatments were applied using the same method as experiment 1. For the nitrogen fertilization treatments, urea was applied at a rate of 1 pound of nitrogen per 1,000 square feet at the beginning of summer and again in midsummer for a total of 2 pounds of nitrogen per 1,000 square

A nitrous oxide (N2O) measurement date during the summer using static chambers mounted on base collars in the soil. A single measurement date required 20 hours.

feet per year and the controlled-release, PCU was applied once at the beginning of summer for a total of 2 pounds of nitrogen per 1,000 square feet per year. Nitrous oxide emissions were measured with static chambers placed over the turf surface and then analyzed with gas chromatography.

Twelve static chambers (right side) were used for sampling N2O across 36 plots on each measurement date.

Results

Results from experiment 1 revealed soil organic carbon increased after the study period, indicating that carbon was sequestered in the turfgrass soil. The average gross carbon sequestration rates for the two treatments were not statistically different at 1,046 kg C ha-1 yr-1 (933 pounds of C per acre per year) and 976 kg C ha-1 yr-1 (871 pounds of C per acre per year) in HMI and LMI, respectively, prior to subtracting HCC (Table 1). Overall, the zoysiagrass golf course fairway turf had an average gross carbon sequestration rate of 1,011 kg C ha-1 yr-1 (902 pounds of C per acre per year). Once the total estimated HCC was included, the average net carbon sequestration rate was 412 kg C ha-1 yr-1 (368 pounds of C per acre per year) and 616 kg C ha-1 yr-1 (550 pounds of C per acre per year) in HMI and LMI, respectively, with no statistical differences.

The HMI had 76% more HCC than the LMI due to nitrogen fertilization and higher irrigation amounts, which led to greater N2O emissions and more mowing events. Therefore, results indicate high- and low-management-input regimes result in similar net carbon sequestration rates in zoysiagrass golf course fairway turf. In addition, both management regimes maintained acceptable turf quality and at least 75% green turf cover during both summers, which included unfertilized zoysiagrass plots receiving only 33% replacement of ETo twice a week with all rainfall excluded for 92 days during the summer (Braun and Bremer, 2019).

Table 1

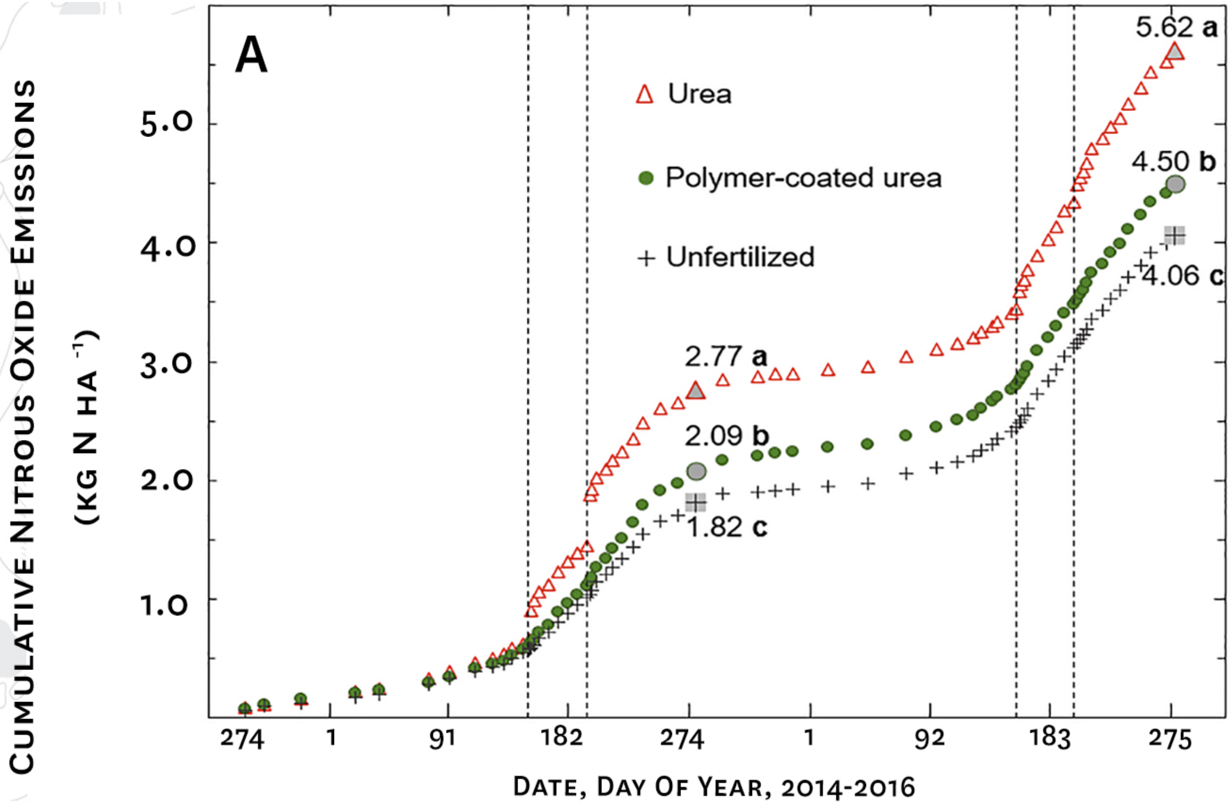
	High management input regime	Low management input regime
Gross SOC Sequestration rate (kg C ha-1 yr-1)	1046 a†	976 a
Hidden carbon costs		
Nitrous oxide emissions HCC (kg CE ha-1 yr-1)‡	351 a	254 b
Mowing HCC (kg CE ha-1 yr-1)§	87 a	49 b
Irrigation HCC (kg CE ha-1 yr-1)§	42 a	30 b
Fertilizer HCC (kg CE ha-1 yr-1)§	127¶	0
Pesticide HCC (kg CE ha-1 yr-1)§	27	27
Total HCC (kg CE ha-1 yr-1)#	634 a	360 b
Net SOC sequestration rate (kg C ha-1 yr-1)††	412 a	616 a

† Within a row, means with different lowercase letters are significantly different according to Fisher's LSD ($P \leq 0.0001$).
‡ Nitrous oxide emissions were converted from kg N_2O ha-1 yr-1 to kg CE ha-1 yr-1.
§ 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).

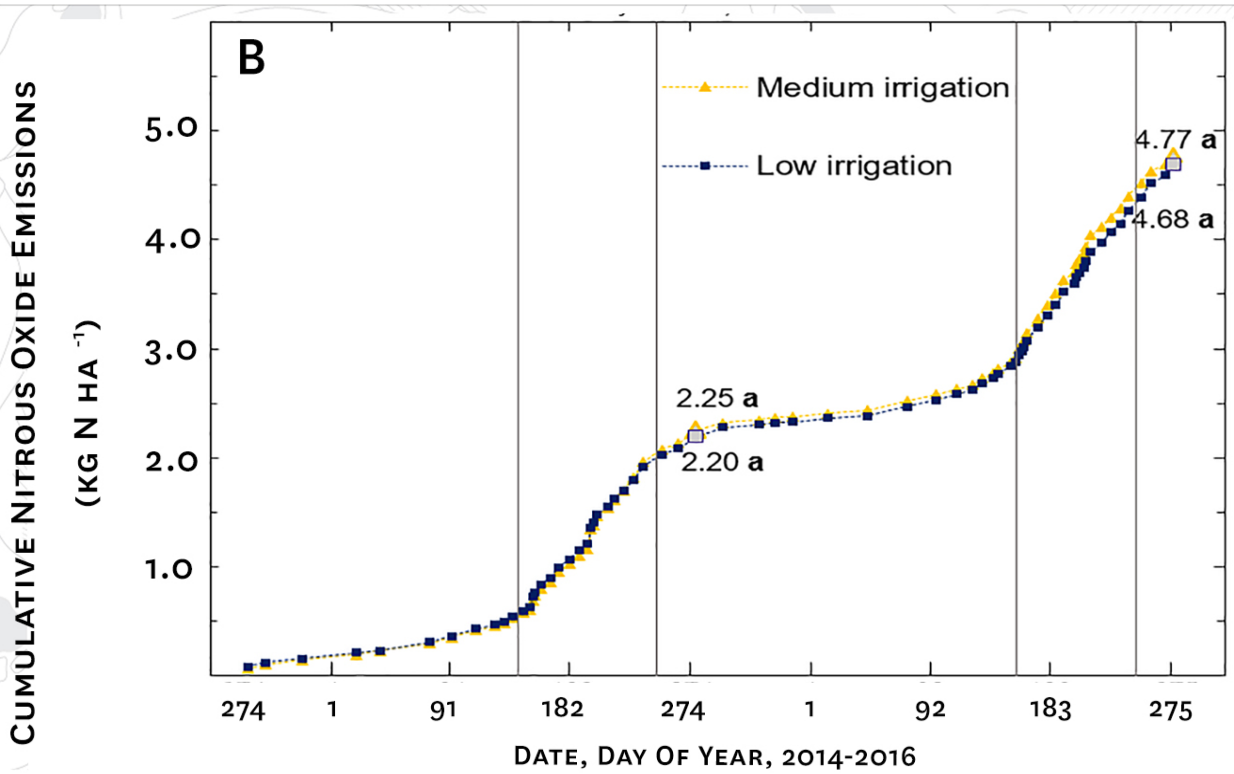
The calculated gross and net soil organic carbon (SOC) sequestration rates using estimates of annual hidden carbon costs (HCC) of measured turf maintenance practices and measured annual nitrous oxide (N2O) emissions in terms of carbon equivalents (CE) in a zoysiagrass fairway.activated by 0.01 inch of rain.

The HMI had 76% more HCC than the LMI due to nitrogen fertilization and higher irrigation amounts, which led to greater N2O emissions and more mowing events. Therefore, results indicate high- and low-management-input regimes result in similar net carbon sequestration rates in zoysiagrass golf course fairway turf. In addition, both management regimes maintained acceptable turf quality and at least 75% green turf cover during both summers, which included unfertilized zoysiagrass plots receiving only 33% replacement of ETo twice a week with all rainfall excluded for 92 days during the summer (Braun and Bremer, 2019).

Results from experiment 2 revealed that N2O emissions decreased with less irrigation; specifically, N2O emissions during two summers were reduced by 6% with 33% ETo replacement (2.71 kg ha-1) versus 66% ETo replacement (2.88 kg ha-1) ($P < 0.001$) (Table 2). Overall, the majority of the differences in daily N2O fluxes and cumulative N2O emissions were due to the nitrogen inputs.



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 (N2O) emissions in terms of carbon equivalents (CE) in a zoysiagrass fairway.activated by 0.01 inch of rain.



In both years, cumulative annual emissions of N2O were significantly greatest in urea-treated plots and least in unfertilized zoysiagrass among the treatments (Table 2 and Figure 1). Cumulative emissions of N2O-N for the entire two-year period were 4.06 kg ha-1 in unfertilized plots and 4.5 kg ha-1 in PCU, which represent reductions of 28% and 20%, respectively, from urea-treated turf (5.62 kg ha-1) ($P < 0.01$). Compared with unfertilized turf, total cumulative emissions of N2O were increased by 38% with urea fertilization and 11% with PCU fertilization. The range of annual N2O emissions (1.82 to 2.85 kg N2O-N ha-1 yr-1) in this study is comparable to the average rate of 2.7 kg N2O-N ha-1 yr-1 reported from other turfgrass systems, which is also similar to rates in agricultural soils (Braun and Bremer, 2018b).

TABLE 2

	Cumulative N_2O emissions		
Source of variation	Total summer periods N_2O-N kg ha^{-1}	Total offseason periods N2O-N kg ha^{-1}	Combined total for entire 2-year period N2O-N kg ha^{-1}
Fertilizer			
Urea	3.59 a†	2.03 a†	5.62 a†
Polymer-coated urea (PCU)	2.53 b	1.97 a	4.50 b
Unfertilized (UF)	2.28 c	1.78 b	4.06 c
Irrigation‡			
Medium (66% ETo)	2.88 a†	1.89	4.77
Low (33% ETo)	2.71 b	1.97	4.68
Fertilizer × irrigation			
Urea × Medium	3.68 a§	1.95	5.63
Urea × Low	3.50 b	2.11	5.61
PCU × Medium	2.68 c	1.96	4.64
PCU × Low	2.37 d	1.99	4.36
UF × Medium	2.29 d	1.75	4.04
UF × Low	2.27 d	1.80	4.07

† Within source of variation, means in column with different letters are significantly different according to Fisher's LSD ($P \leq 0.01$).
‡ Medium irrigation level was 66% evapotranspiration (ET_0) replacement and low irrigation level was 33% ET_0 replacement. Irrigation treatments were only applied during the summer periods.
§ Within source of variation, means in column with different letters are significantly different according to Fisher's LSD ($P \leq 0.05$).

The calculated gross and net soil organic carbon (SOC) sequestration rates using estimates of annual Analyses of fertilizer main effect, irrigation main effect, and fertilizer × irrigation interaction on two-year total cumulative nitrous oxide emissions for the summer periods (June – August), offseason period (September – May), and the combined total of the entire two-year period.

Over the two-year study, the percentage of applied nitrogen fertilizer emitted as N2O in this study was 2.3% from PCU and 2.9% from urea fertilizer. The highest fluxes and majority of emissions occurred in the summer because of the fertilization events and, presumably, higher soil temperatures (Braun and Bremer, 2018a). There were spikes after applications of urea, but increases were much smaller after application of PCU (Braun and Bremer, 2018a). Results from this study indicate that use of controlled-release fertilizers, such as PCU, instead of a quick-release fertilizer and/or less irrigation will reduce N2O emissions in turfgrass. Notably, all fertilizer and irrigation treatments maintained acceptable turf quality and high levels of percent green cover (Figure 2; see also Figure 1 in Braun and Bremer, 2019); however, PCU resulted in more consistent turf quality and green cover compared to urea-treated and unfertilized plots.

Figure 2-A

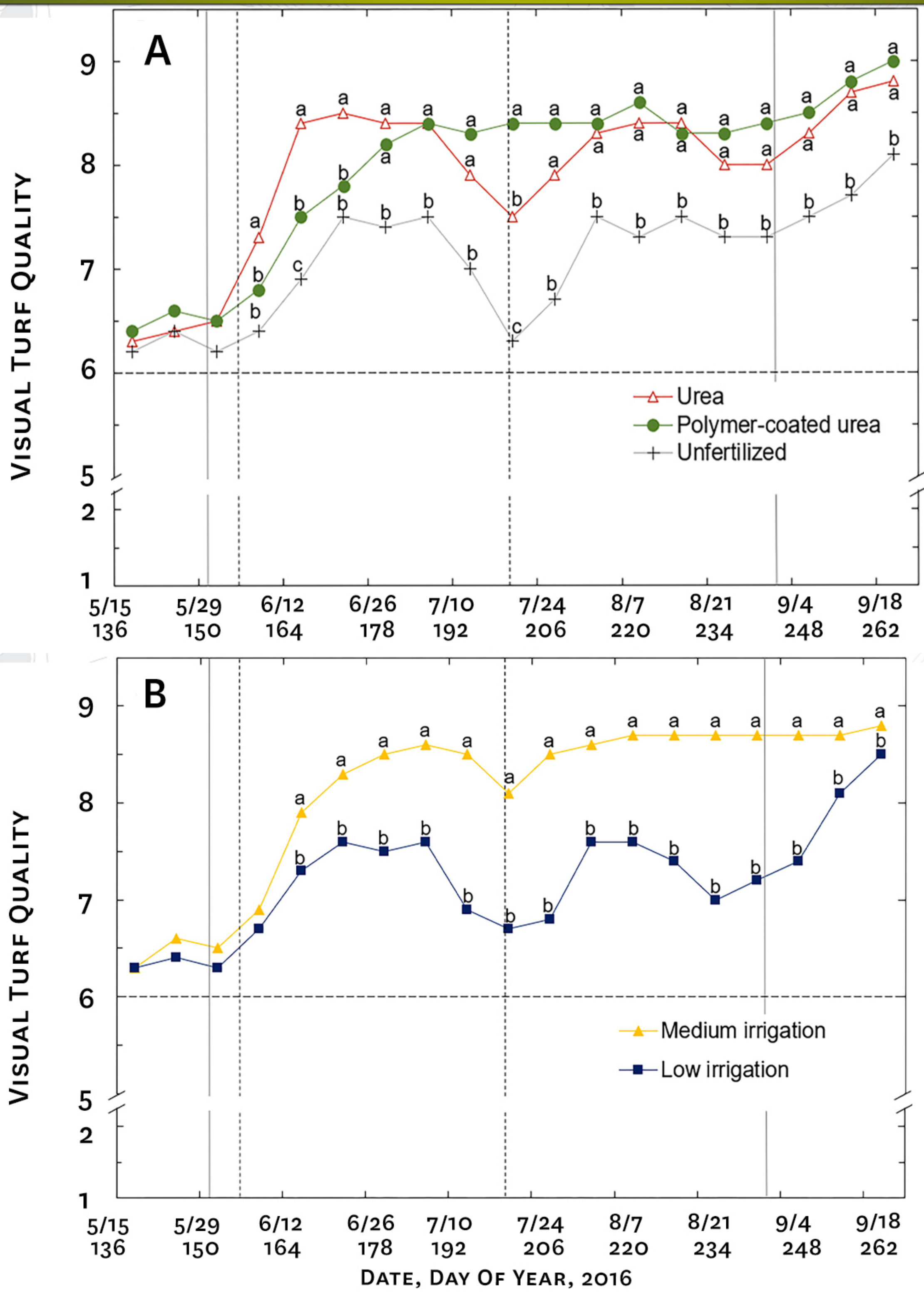


Figure B Caption: Effects of the (A) fertilizer main effect and (B) irrigation main effect on visual turf quality of zoysiagrass in 2016. Solid vertical lines represent the summer period when the rainout shelter was activated and irrigation treatments were applied. Dashed vertical lines at June 6 represents fertilization with urea at 49 kg N ha-1 and polymer-coated urea at 98 kg N ha-1 and dashed vertical line at July 20 represents the second urea application at 49 kg N ha-1. Dashed horizontal line at a visual rating of 6 signifies minimum rating for acceptable turf quality. Within each main effect, means at each date with the same letter or no letters are not significantly different according to Fisher's LSD ($P \leq 0.05$).

Currently, USGA-funded research at Kansas State University is building upon data from our research results presented above to develop simulation models of N_2O emissions and carbon sequestration in zoysiagrass fairway turf using the DAYCENT model. Research objectives are to calibrate the DAYCENT model to predict and estimate the long-term impacts of turf management practices, as well as other maintenance expenses, on N_2O emissions and carbon sequestration in a zoysiagrass golf course fairway.

Discussion

Results from these USGA-funded experiments indicate the development and application of management practices, such as less irrigation and the use of controlled-release fertilizers, may reduce N_2O emissions while promoting sequestration of atmospheric carbon at similar rates to high-management-input regimes. Such practices could also save time and labor for golf course superintendents through reduced irrigation, fewer fertilizer applications, and a potential reduction in mowing requirements. Results also indicate the importance of factoring the hidden carbon costs of turf maintenance practices into net carbon sequestration rates. The use of these specific management practices could improve a golf course's efforts toward environmental stewardship. .

Turfgrass provides significant economic, environmental, and human benefits but is sometimes criticized as being environmentally unfriendly, for example because of its use of water and fertilizers. This research revealed specific management practices that can help minimize the use of water and nitrogen fertilization in turfgrasses and reduce the amount of greenhouse gases (CO_2 and N_2O) in the atmosphere, via increased carbon sequestration and reduced N_2O emissions. For example, less irrigation not only reduced N_2O emissions but also conserved water while still promoting sequestration of atmospheric carbon. Also, fertilizing with a controlled-release nitrogen fertilizer – polymer-coated urea – not only reduced N_2O emissions, but also consistently maintained higher turfgrass visual quality and green turf cover than urea. Interestingly, at the low irrigation level, N_2O emissions were as low in zoysiagrass fertilized with a polymer-coated nitrogen source as they were in unfertilized turf. Finally, other potential benefits of fertilizing with controlled-release nitrogen include increased nitrogen availability to the turf by releasing nitrogen as the plant needs it while losing less nitrogen to the environment through volatilization or leaching.

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