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Creeping Bentgrass Growth Response to Elevated Soil Carbon Dioxide

B. Todd Bunnell[1], Lambert B. McCarty[2], Roy B. Dodd[3], and Hoke S. Hill[4]
Clemson University, Clemson, SC 29634-0375

James J. Camberato[5]
Clemson University, Florence, SC 29506

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Abstract. **Increased soil moisture and temperature along with increased soil microbial and root activity during summer months elevate soil CO_2 levels. Although previous research has demonstrated negative effects of high soil CO_2 on growth of some plants, little is known concerning the impact high CO_2 levels on creeping bentgrass (*Agrostis palustris* Huds.). The objective of this study was to investigate effects of varying levels of CO_2 on the growth of creeping bentgrass. Growth cells were constructed to U.S. Golf Association (USGA) greens specification and creeping bentgrass was grown in the greenhouse. Three different levels of CO_2 (2.5%, 5.0%, and 10.0%) were injected (for 1 minute every 2 hours) into the growth cells at a rate of 550 $cm^3 \cdot min^{-1}$. An untreated check, which did not have a gas mixture injected, maintained a CO_2 concentration <1%. Gas injection occurred for 20 days to represent a run. Two runs were performed during the summer of 1999 on different growth cells. Visual turf quality ratings, encompassing turf color, health, density, and uniformity, were evaluated every 4 days on a 1–9 scale, with 9 = best turf and <7 being unacceptable. Soil cores were taken at the end of each run. Roots were separated from soil to measure root depth and mass. Turf quality was reduced to unacceptable levels with 10% CO_2, but was unaffected at lower levels over the 20-day treatment period. Soil CO_2 ≥2.5% reduced root mass and depth by 40% and 10%, respectively.**

The transition zone is the area found in the eastern and central United States where both cool (C_3) and warm (C_4) season turfgrasses can be grown, but neither is well adapted to the climate. Hot, humid summers make growing cool season turfgrass species, particularly creeping bentgrass, challenging (Christians, 1998). Creeping bentgrass is physiologically adapted to summertime air temperatures of 16 to 24 °C (Beard, 1997). Yet, temperatures in the transition zone often exceed 30 °C, resulting in stressful growing conditions.

Summer bentgrass decline is an all-inclusive term describing the deterioration of bentgrass quality during summer months. Several environmental and plant physiological factors are involved with summer bentgrass decline. Factors include compaction from foot traffic and high temperatures and humidity causing heat stress, increased disease incidence, and excessive soil moisture levels. These can combine to create an overlooked problem, poor soil oxygenation and increased levels of soil CO_2.

Gases make up ≈20% to 30% of a typical soil volume (Brady, 1984, Hillel, 1980). The soil atmosphere is defined as "the gaseous phase of the soil, being that volume not occupied by solid or liquid" (Bremner and Blackmer, 1982). Generally, the composition of soil air is similar to that of the atmosphere with two major exceptions, O_2, and CO_2. Oxygen and CO_2 fluctuate in the soil, with an increase in CO_2 relating to a decrease in O_2 (Williamson, 1964; Hillel, 1980; Bremner and Blackmer, 1982).

Root cells respire, thus using O_2 and releasing CO_2. Oxygen is required by roots for growth and water and nutrient uptake (Williamson, 1964). Plants grown in soils with low soil O_2 concentrations will experience a loss of turgor pressure and increased wilting (Letey et. al., 1961).

Turfgrass species have a relatively high tolerance to low soil O_2 availability (Williamson, 1968). Oxygen availability in the soil is determined by the oxygen diffusion rate (ODR) which measures the amount of soil O_2 that physically exchanges with atmospheric O_2. Creeping bentgrass grown with no other environmental stresses can survive in soils with ODR levels as low as 5.0×10^{-8} $g \cdot cm^{-2}$/min, whereas most plants require an O_2 delivery of 1.5×10^{-7} to 2.0×10^{-7} $g \cdot cm^{-2}$/min (Williamson, 1968). During summer months, root O_2 requirements increase with high temperatures stimulating root and microbial respiration (Waddington and Baker, 1964; Williamson, 1964). Huang et al. (1998) noted that at high temperatures (35 to 25 °C), creeping bentgrass root viability and root dry matter were reduced when ODR levels were only 2.0×10^{-7} $g \cdot cm^{-2}$/min. The relationship between turf quality and ODR, however, has not yet been defined over a wide range of environmental conditions.

Carbon dioxide is found at very low levels in atmospheric air (≈0.03%). However, soil CO_2 can be 10–100 times greater than atmospheric CO_2 (Hillel, 1980; Bremner and Blackmer, 1982). Roots and microbes produce CO_2 with the uptake of carbon (C) and O_2 during respiration. Increased soil microbial activity occurs with increased temperature, often elevating CO_2 concentrations during warmer weather. In poorly aerated soils, CO_2 can potentially elevate to toxic levels (Williamson, 1968). Well-aerated soils generally have less potential to accumulate high CO_2 concentrations, since atmospheric O_2 readily diffuses into the soil, displacing CO_2.

The toxicity of CO_2 is not fully understood. The most widely accepted hypothesis is high CO_2 levels decrease the cytoplasmic pH of root cells, thereby interfering with water and nutrient uptake and stunting root growth (Chang and Loomis, 1945; Williamson, 1964). Distilled water saturated with CO_2 has a pH ≈4.0 due to the formation of carbonic acid (H_2CO_3) (Chang and Loomis, 1945). Although no work has been performed on creeping bentgrass and elevated CO_2, previous research shows soil CO_2 >6% to be toxic to growth of broad bean (Williamson, 1968).

Minimal research has been performed on the variable soil concentrations of O_2 and CO_2 on C_3 plants, such as creeping bentgrass. The objective of this study was to determine the effects of elevated soil CO_2 on the root growth and turf quality of creeping bentgrass.

Materials and Methods

Growth cells were constructed to simulate a standard layered golf green (Fig. 1). Polyvinyl chloride (PVC) pipe (25 cm in diameter) was cut to 40 cm in length and the base was fitted with a 25-cm-diameter PVC cap. Drainage holes were cut in the center of each cap and covered on the inside of the cap with expanded metal appropriately sized to prevent gravel from clogging the drain hole. Drain holes were fitted with a 2-cm female adapter on the outside of the cap and connected to 2-cm PVC pipe. Individual drains of three growth cells were connected with 4-cm-diameter PVC pipe. On one end of the 4-cm pipe was a p-trap allowing water to drain but did not allow air to pass. On the other end of the pipe a solenoid valve regulated the timing and frequency of gas entry. To prevent water and air leakage, silicon seals were used in all fittings. Aluminum frames were used to support growth cells.

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[1] Graduate Assistant, Dept. of Horticulture. E-mail: btbunne@clemson.edu

[2] Professor, Dept. of Horticulture. E-mail: bmccrty@clemson.edu

[3] Professor, Dept. of Agriculture and Biological Engineering. E-mail: rdodd@clemson.edu

[4] Professor, Dept. of Experimental Statistics. E-mail: hhill@clemson.edu

[5] Associate Professor, Dept. of Crop and Soil Environmental Science. E-mail: jcmbrt@clemson.edu

Table 1. Particle size distribution percentages of sand used in growth cells compared with USGA recommendations for golf greens.

	Soil separation (%)			Sieve size/sand fraction sand particle diameter (% retained)					
Sample	Sand	Silt	Clay	Gravel 2 mm	Very coarse 1 mm	Coarse 0.5 mm	Medium 0.25 mm	Fine 0.15 mm	Very fine 0.05 mm
Clemson Mix	98.0	1.0	1.0	0.1	3.2	27.9	51.7	12.0	3.1
USGA Value	≥92	≤3	≤3	≤3 gravel ≤10 combined		≥60		20	≤5

Soil profile construction followed U.S. Golf Association (USGA) recommendations (USGA, 1993) (Table 1). Pea gravel (10 cm) covered the exit drain, topped by 30 cm of a mix of 85 sand: 15 peat (v/v) filled each cell. The particle size distribution of the sand met USGA recommendations and was uniformly compacted with a bulk density of 1.41 g·cm^{-3}.

On 21 Jan. 1999, cells for both experimental runs were seeded with 5.9 g·m^{-2} 'Crenshaw' creeping bentgrass and rolled with a PVC pipe to create good seed to soil contact for consistent germination. Grass establishment involved watering of 0.5 cm·d^{-1} split evenly between 0800 HR, 1200 HR, and 1500 HR. First signs of germination were 4 d after seeding and grass was cut by hand with scissors at a height of 1 cm for 14 d. Two weeks following germination, routine fertilization, mowing, and watering practices were initiated. Mowing was performed five times weekly with a motorized hand held trimmer at a height of 0.6 cm and cells fertilized biweekly with 12N–1.8P–6.6K liquid fertilizer (Green Relief, Jacksonville, Fla.) N at 1 g·m^{-2}, P at 0.4 g·m^{-2}, and K at 0.8 g·m^{-2}. Growth cells received two daily applications of water (1000 HR and 1500 HR) equaling 0.5 cm·d^{-1} to avoid wilting point. Fungicides were applied as needed for disease control. Azoxystrobin [methyl (E)-2-{2-[6-(e-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate] (Heritage; Zeneca Ag Products, Wilmington, Del.) and chlorothalonil (tretachloroisophthalonitrile) (Daconil Ultrex, Zeneca Ag Products, Wilmington, Del.) were applied ai at 0.1 and 0.93 g·m^{-2}, respectively. Box fans were installed to stimulate air movement in turf canopy to decrease humidity and heat stress.

Treatments consisted of varying levels of $CO_2 : O_2$. Carbon dioxide levels were inversely linear to O_2. Treatments included an untreated check (no air injection), 2.5%, 5.0%, and 10.0% CO_2 mixed with 17.5%, 15.0%, and 10.0% O_2, respectively, along with standard 80% N_2. Gas mixtures were injected into the drainlines opposite the side of the p-trap to force the mixtures upward into the growth cells. The connecting drainlines delivered the gas to three growth cells representing the experimental positions. In order to maintain desired levels of CO_2, gases were injected for 1 min every 2 h to growth cells at a flow rate of 5500 cm^3·min^{-1}. An electric solenoid valve regulated gas entry. Preliminary work included monitoring soil gas concentrations (O_2 and CO_2) after purging to determine the rate and frequency of gas entry. Untreated growth cells maintained a CO_2 concentration of <1%. Gas levels (O_2 and CO_2) were monitored with a portable infra-red gas analyzer (model #1810-2772; Soil Scientific, Deep River, Conn.) daily from growth cells for assurance of soil atmosphere levels consistent with injected concentrations. Gas levels were consistently maintained within 0.5% of injected concentration. Treatments were imposed for 20 d during runs 1 and 2 on 20- and 26-week-old bentgrass, respectively. Separate runs occurred 11 June to 30 June 1999 and 24 July to 12 Aug. 1999. Runs were performed on different growth cells. Maximum ambient temperatures were maintained between 35 to 40 °C to provide a stressful environment for creeping bentgrass. Minimum nighttime temperatures ranged between 17 to 20 °C.

Visual ratings of turf quality, comprised of color, health, density, and uniformity, were determined every 4 d. Turf quality was rated on a 1–9 scale with 9 = best turf quality. Turf quality was considered unacceptable when <7. After completion of each experimental run, a 5-cm-diameter × 30-cm-deep soil core was extracted. Root depth (cm) was measure by averaging the two deepest roots within each soil core prior to washing. Root mass was measured after washing sand and organic matter from the roots with an automated air and water pressurized root washer (Smucker et al., 1982). Samples were dried at 80 °C for 3 d and weighed (g).

The study was a randomized complete-block design (RCBD) with CO_2 level and experimental position representing the two factors investigated. Experimental position refers to growth cell location within CO_2 level. In the study, three experimental positions were established with position 1 being closest to gas entry point (Fig. 1). Two runs were performed representing the two replications, which were the blocks. Root data and turf quality data were analyzed using analysis of variance (ANOVA) general linear model procedure (GLM) (SAS Institute, Cary, N.C.). Treatment (CO_2) and experimental position main effects and the treatment by experimental position interaction were tested. Means separations were performed on significant factors using LSD. An $\alpha = 0.05$ was used for turf quality interpretations. Due to inherent variability in similar root studies, an $\alpha = 0.10$ was used for root data testing (Wiecko et al., 1993).

Results and Discussions

Results of ANOVA of root data showed a significant treatment effect with root mass ($P = 0.0293$) and root depth ($P = 0.0210$), but no significant experimental position or treatment by experimental position effects. Root mass and depth were reduced with elevated levels of soil CO_2. A 40% [percentage calculated as: (treated-untreated)/untreated)] decrease in root mass occurred with soil CO_2 levels ≥2.5% (Fig. 2). A 10% decrease in root depth also resulted from CO_2 levels ≥2.5% (Fig. 3). Creeping bentgrass exposure to elevated concentrations of 2.5%, 5%, and 10% soil CO_2 for 20 d reduced root mass and depth. Additional research should investigate long-term elevated soil CO_2 exposure of creeping bentgrass putting greens.

Results of ANOVA of turf quality data showed a significant treatment effect ($P < 0.003$)

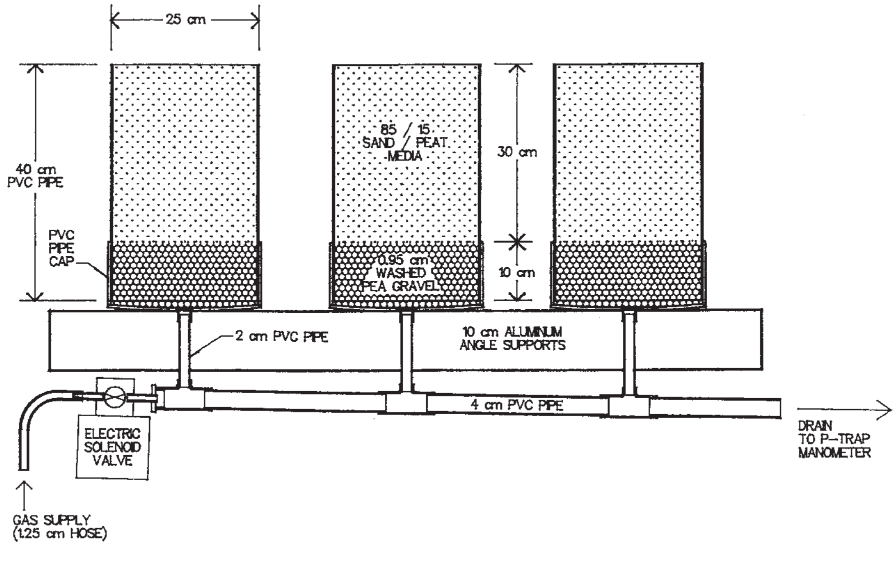

Fig. 1. Cross section of growth cells showing gas injection piping and experimental position representing sequence of growth cell from gas injection point.

for all rating periods except 4 days after initiation, but no significant experimental position or treatment by experimental position effects. Turf quality was reduced by elevated concentrations of soil CO_2. After 1 week of 10% CO_2, turf quality was unacceptable (Fig. 4). Turf quality was reduced to <7.0 with 10% CO_2 from day 8 to 18. The 5% CO_2 concentration reduced turf quality from the untreated however it still maintained acceptance. Carbon dioxide levels of 2.5% did not affect turf quality. Decreased turf quality with 5% and 10% soil CO_2 may have resulted from toxic levels of CO_2. No decrease in turf quality occurred with the 2.5% CO_2 concentration, however a decrease in root mass and depth did occur. Higher O_2 concentration associated with the 2.5% CO_2 possibly provided adequate soil oxygenation for root respiration, improving turf quality. Additional physiological stress, such as temperature, may have attributed to lower CO_2 levels damaging creeping bentgrass.

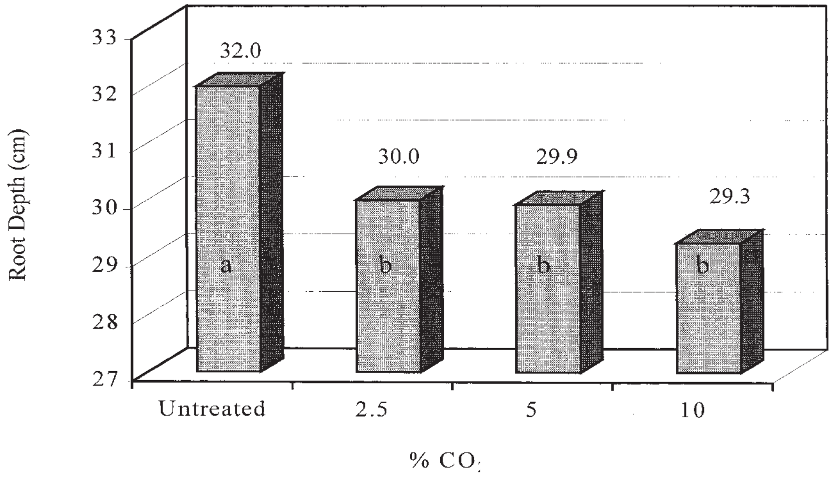

Fig. 2. Root mass of creeping bentgrass 20 d following initiation of elevated soil CO_2. Within each CO_2 level, means followed by day after gas treatment, means followed by the same letter are not significantly different according to Fischer's protected LSD at $\alpha = 0.10$.

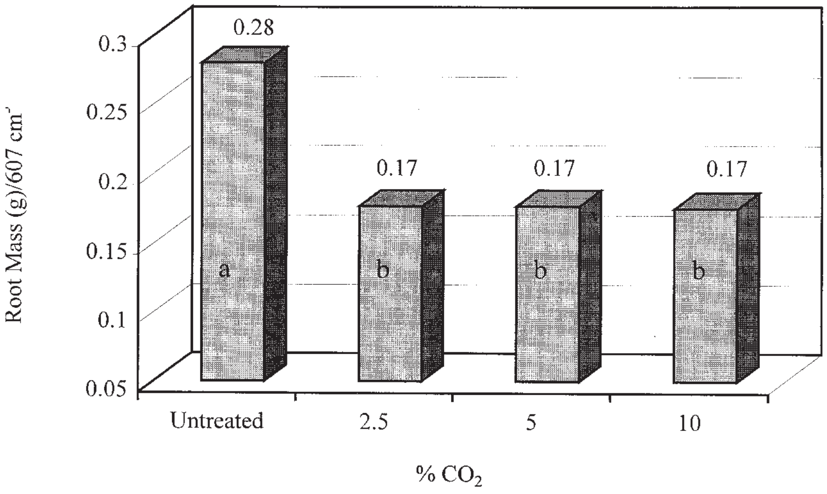

Fig. 3. Root depth of creeping bentgrass 20 d following initiation of elevated soil CO_2. Within each CO_2 level, means followed by the same letter are not significantly different according to Fischer's protected LSD at $\alpha = 0.10$.

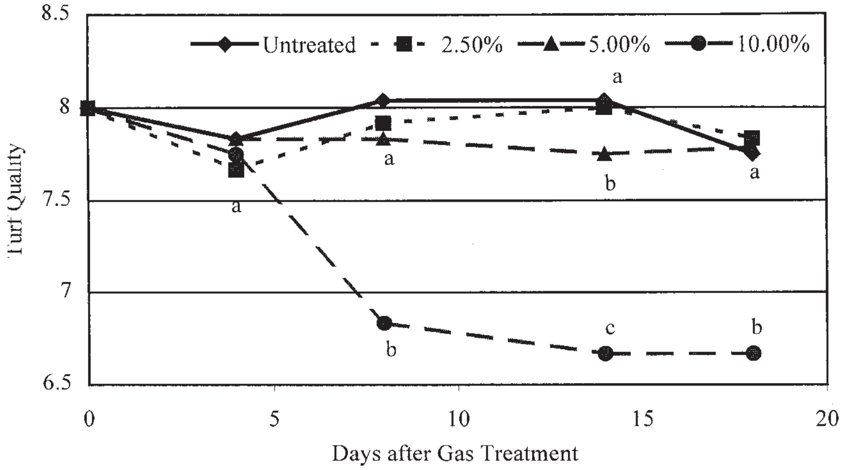

Fig. 4. Visual rating of creeping bentgrass turf quality with various levels of elevated soil CO_2. Within each CO_2 level, means followed by the same letter are not significantly different according to Fischer's protected LSD at $\alpha = 0.05$.

Conclusions

High temperatures and soil moisture levels generally increase potential for high CO_2 concentrations and limited O_2 in golf course putting greens. This research demonstrated elevated levels of soil CO_2 are detrimental to creeping bentgrass root growth and turf quality. Decreased root mass and length followed 20 d of soil CO_2 equaling or exceeding 2.5%. Unacceptable turf quality was found with 10% soil CO_2. Similar inflated levels in a golf course green may potentially cause greater bentgrass damage due to increased stress incurred from other physical and biological stresses associated with golf course management. Further research will investigate elevated soil CO_2 effects at various temperatures and soil moisture regimes. Current and additional research will determine the concentration of soil CO_2 that is toxic on the growth and performance of creeping bentgrass putting greens.

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