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March 4, 2004

## Irrigation of a Sand-Based Bentgrass Greens with Ozonated Water.


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## ABSTRACT

During the hot days of summer, grasses can suffer from lack of oxygen in the rooting zone. The objective of this study was to evaluate the effect of water ozonation and aeration on turf growth and root zone chemistry. Bentgrass cores were collected from a sand-based bentgrass nursery and placed in PVC columns designed to collect leachate water. Cores were placed in a greenhouse and irrigated with 1) tap water, 2) aerated water (12 mg/L dissolved oxygen (DO)), or 3) ozonated water (aerated plus 0.5 mg/L ozone). Leachate was periodically collected and analyzed for pH, EC, DOC and nutrients. Grass clippings were weighed and analyzed for total N and P. Roots were periodically collected from selected cores to determine root distribution. At 40 and 90 days after initiation of water treatments, bentgrass irrigated with ozonated water had a higher chlorophyll index than bentgrass irrigated with tap water. After 2 to 3 months treatment, grass clipping weights were significantly greater for the cores irrigated with ozonated water, and to a lesser extent, aerated water. Early leachate samples showed no effect due to water treatments, but as average daily temperatures increased, we observed elevated NO3-N and EC levels in leachate from aerated and ozonated samples, suggesting increased mineralization of organic matter in those bentgrass cores.


## INTRODUCTION

Ozone ($O_3$) is a reactive molecule that is produced from atmospheric oxygen ($O_2$) by passing air through a high voltage corona discharge. Ozone has been used for more than 100 years to disinfect drinking water. Other uses include the treatment of wastewaters from municipalities or process waters from various commercial operations, such as food processors and laundries. Ozone can be used to degrade humic substances in water and reduce turbidity (Amirsardari et al., 1998; Gracia et al., 1996). More recently, ozone has been added to irrigation waters with reported benefits that include increased water infiltration, increased disease resistance, and reduced need for fertilizers (Raub et al., 2001). Although there is limited scientific data to demonstrate these benefits, the results are consistent with the predicted effects one would see

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when adding a strong oxidizer, such as ozone, to soil. Ozone will oxidize soil organic matter and plant residues, thus releasing essential plant nutrients. Oxidation of organic matter coatings on clay particles could change their surface charges and cause them to flocculate (i.e., clump together). This effect could improve water infiltration by preventing clay dispersion. The process of ozonation also produces nitric acid ($HNO_3$), which could be a source of nitrogen for plants. The effects of using ozonated water in a sand-based growing media, such as a putting green, are unknown. Although there may be beneficial short-term effects, it is possible that long-term effects would be detrimental due to the breakdown of organic matter. We need a greater understanding of the effects of ozonated water on chemical and physical properties in the rooting zone of a sand-based growing medium so that we can make educated decisions on how to use ozonated water in managing golf course greens. From a practical standpoint, we need to know the duration of the effects of ozonation on water chemistry.

## OBJECTIVES

1. The primary objective of this study was to determine the effects of ozonated irrigation water on turf grass growth and on soil physical and chemical properties in a sand-based green. Specifically, we evaluate the effect of ozonated water on:
    a. above-ground bentgrass clipping weights
    b. bentgrass root growth and distribution
    c. nutrient cycling and leachate chemistry
    d. turf growth (verdure) and development
    e. water infiltration characteristics and water holding capacity of soil

## MATERIALS AND METHODS

***Set up:*** A greens cup cutter was used to collect 72 cores measuring 4-in diameter by 6-in depth from a bentgrass nursery at the Trophy Club Golf Course in Trophy Club, Texas. Thirty-six cores were collected in August 2001 and another 36 cores were collected 3 weeks later. Each core was placed in a specially designed PVC column and transferred to a greenhouse at Texas A&M University – Dallas. The PVC columns were designed so that leachate water could be collected for chemical analysis (Fig. 1). Cores were fertilized with $NH_4SO_4$ at a rate of 1lb N per 1000ft$^2$ and this fertilizer application was repeated approximately every two months. The bentgrass cores were watered daily with greenhouse tap water.

***Water Treatments:*** On January 17, 2002, bentgrass columns were divided into three groups of 24 columns. From this date forward for the next 12 months, each group was exclusively water with one of three water treatments. One group was watered with normal tap water, the second group with aerated water, and the third group with ozonated water. Ozonated water was generated using an Oxion Ozone generator (Thunderstorm Technology, Inc., Flowermound, Texas), which passes ambient air through a high voltage corona discharge column before introducing the ozonated air into irrigation water with a venturi-type aspirator (Fig. 2). Ozone concentrations were measured at various flow rates using the indigo colorimetric method (Greenberg et al., 1992). Aerated water was generated with the same unit by decreasing the voltage on the corona discharge tube to zero.  Dissolved oxygen concentrations in the normal water ranged from 6 to 8 mg/L, and were increased to 12 to 14 mg/L in the aerated and ozonated water.  Dissolved oxygen was measured with a dissolved oxygen meter (Orion Model 862A, Orion Research, Inc., Berverly, MA).

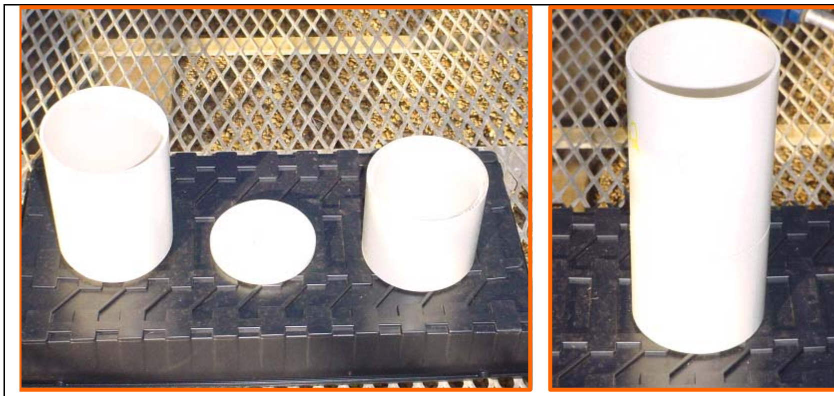

Fig. 1.  Unassembled (A) and assembled (B) PVC leaching columns prior to inserting putting green soil cores.

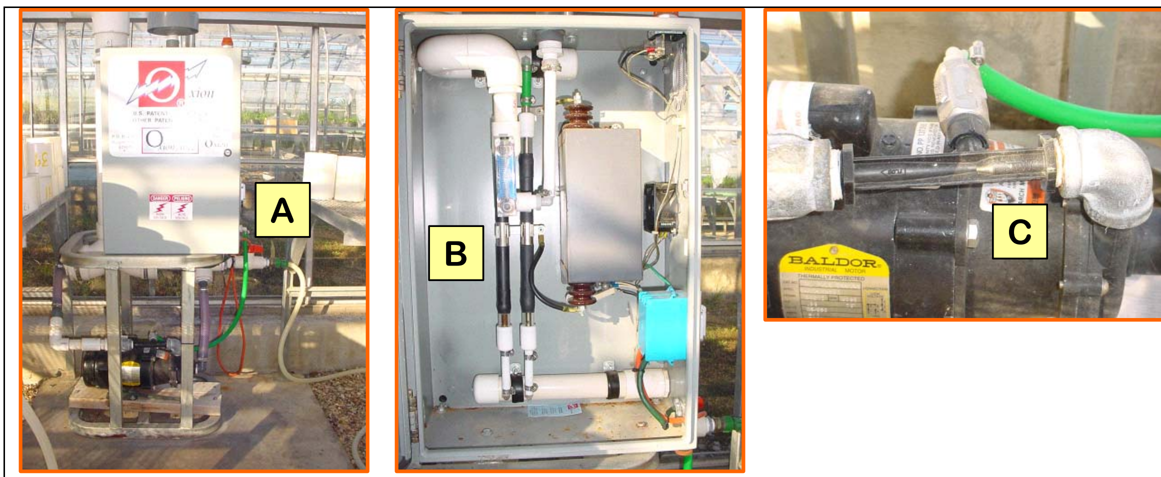


Fig. 2.  Ozonated water was generated with an Oxion unit (A) by passing ambient air through high voltage corona discharge tubes (B) and then introducing the ozonated air into the water with a venture-type aspirator (C).

***Grass measurements:*** Chlorophyll content is a good indicator of the overall nutrient status of a plant, especially nitrogen.  At 40 and 90 days after initiating water treatments, we measured the relative chlorophyll content of the bentrass cores using a Fieldscout CM1000 Chlorophyll meter (Spectrum Technologies, Inc., Plainfield, Illinois).  Chlorophyll content was measured at five spots on the surface of each bentgrass core and the five readings were averaged to obtain a single relative chlorophyll value.

Aboveground bentgrass was clipped to a height of ½ inch whenever growth reached 1 to 1.5 inches. On average, grass was clipped every 4 to 5 weeks but actual time between clippings depended on a variety of conditions including frequency of fertilization and watering as well as seasonal changes in greenhouse growing conditions. Grass clippings were dried at 60°C and weighed to determine aboveground biomass production. At 103 and 128 days after initiating treatments, grass clippings were ground to pass a 1mm sieve and analyzed for total nitrogen content. Additionally, grass clippings from 157 and 191 days after initiating water treatments were analyzed for total N, P, K, Ca, Mg, Na, Zn, Fe, Cu, and Mn.

***Leachate chemistry:*** On three occasions after initiating water treatments, leachate water was collected and analyzed for nitrate ($NO_3$-N), orthophosphate ($PO_4$-P), electrolytic conductivity (EC), and pH. On the first two occasions, 300 mL of the appropriate water treatment was added to each column, but only 150 mL was used for the third leaching event. Excess water was allowed to drain from the bentgrass cores for several hours before leachate was removed from the lower column reservoir (Fig. 1). Nitrate, EC, and pH were measured on unfiltered leachate and $PO_4$-P was measured on leachate filtered through a 0.45μm cellulose nitrate membrane filter.

***Root mass:*** Four soil cores were removed from each treatment at 70, 171, and 274 days after initiation of water treatments. Each core was divided into the crown and three depth increments of 0-1.5, 1.5-3.0, and 3.0-4.5 inches (0-3.8, 3.8-7.6, and 7.6-11.4 cm). Roots were separated from the sand growing medium by washing, dried at 60°C, and then weighed in order to determine root distribution with depth.

***Root zone mix:*** In order to evaluate the effect of water aeration and ozonation on organic matter content of the sand-based root zone mix, we determined organic matter content of the root zone mix by measuring loss of weight from a 0.5 gram sample after heating at 550 C for 4 hours (loss on ignition). All visible root residues were removed from the sample before the procedure was carried out. Soil organic matter was first measured at 0-1.5, 1.5-3.0, and 3.0-4.5 inches depth on samples collected 170 days after initiating water treatments. Soil organic matter was measured again in the upper 1.5 inches of the bentgrass cores 12 months after initiating water treatments.

## RESULTS AND DISCUSSION

**Ozone Concentration:** Ozone concentration in the irrigation water varied with flow rate through the ozone generator (Fig. 3). Ozone concentration in the irrigation water was 0.2 mg $L^{-1}$ when the greenhouse spigot was opened to allow a maximum flow of 24 L $min^{-1}$. Ozone concentration increased to approximately 0.8 mg $L^{-1}$ as flow rate was decreased to 3 L $min^{-1}$. We used a flow rate of approximately 5 L/min when watering the bentgrass cores, resulting in an ozone concentration of 0.7 to 0.9 mg/L. Maier (1984) reported that when treating drinking water,

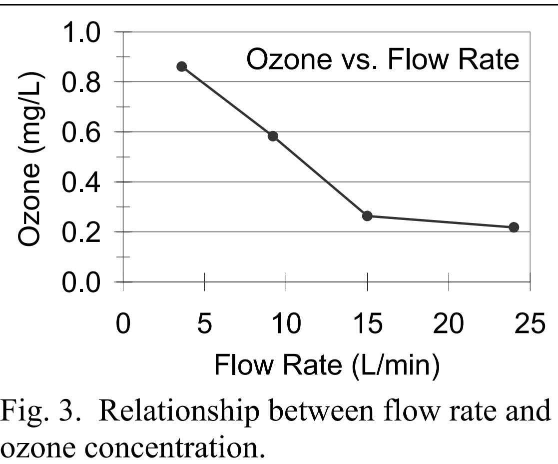

Fig. 3. Relationship between flow rate and ozone concentration.

ozone concentrations of 0.5 to 1.5 mg/L resulted in maximum flocculation of colloidal material.

**Leachate Chemistry:** Water treatments had their greatest effect on $NO_3$-N concentrations in leachate from the bentgrass cores, but the effect was not apparent at every sampling date (Table 1). There was no difference in leachate $NO_3$-N concentrations 18 days after initiating the water treatments, but after 61 and 158 days, both the aerated and ozonated treatments had higher leachate $NO_3$-N concentrations than the control. At 158 days, leachate $NO_3$-N concentrations for the ozonated water treatment were significantly higher than both the aerated and control treatments. There was significantly less $PO_4$-P in leachate from the aerated water treatment at 61 days after initiating water treatments, but no significant differences at the other sampling dates. Electrolytic conductivity (EC) was mostly unaffected by water treatments and pH was significantly lower for the ozone water treatment at 158 days after initiation of treatments. Raub et al. (2001) reported lower pH and higher electrolyte concentrations in drainage water from agricultural soils treated with ozonated water compared to tap water. However, they used water with an ozone concentration of 10 mg $L^{-1}$, whereas the concentration in our study was much lower (0.7 to 0.9 mg $L^{-1}$).

Table 1. Effect of water treatments on leachate chemistry at various times after initiation of treatments. For each date, treatment means followed by the same letter are not significalty different (Duncan's MRT, $p \leq 0.05$).

| Treatment | NO3-N | Ortho-P | EC | pH |
|---|---|---|---|---|
| | (mg $kg^{-1}$) | | (dS $m^{-1}$) | |
| | 2/4/02 (18 DAIT†) (4 DALFA‡) | | | |
| Control | 10.0 a | 0.13 a | 1203 a | 7.92 a |
| Aerated | 9.5 a | 0.16 a | 1148 a | 7.91 a |
| Ozonated | 10.1 a | 0.14 a | 1174 a | 7.91 a |
| | 3/19/02 (61 DAIT) (47 DALFA) | | | |
| Control | 7.8 b | 0.72 a | 562 a | 7.77 a |
| Aerated | 8.7 a | 0.38 b | 588 a | 7.78 a |
| Ozonated | 9.6 a | 0.53 ab | 572 a | 7.70 a |
| | 6/18/02 (149 DAIT) (49 DALFA) | | | |
| Control | 33.1 c | 0.17 a | 722 ab | 8.44 a |
| Aerated | 36.6 a | 0.16 a | 713 b | 8.39 ab |
| Ozonated | 34.8 b | 0.25 a | 753 a | 8.33 b |

† Days after initiation of water treatments
‡ Days after most recent fertilization with $NH_4SO_4$ at 1 lb N per 1000$ft^2$.

**Bentgrass Growth:**

Chlorophyll content can be a good indicator of a plant's general health and nutritional status. Relative chlorophyll content of bentgrass irrigated with aerated and ozonated water was significantly higher than control bentgrass 40 days after initiating water treatments (Fig. 4). At 90 days, only bentgrass irrigated with ozonated water had higher relative chlorophyll content than the control bentgrass. It is possible that increased relative chlorophyll contents in bentgrass irrigated with ozonated, and to a lesser extent, aerated water, was due to release of nutrients by increased mineralization of organic residues in the crown and surface layer of the bentgrass cores. Raub et al. (2001) found that ozonated water increased the concentration of electrolytes, including nitrate and ammonium, in soil leachate water. It is likely that increased soluble nutrients in the bentgrass cores irrigated with ozonated and aerated water were taken up and utilized by bentgrass.

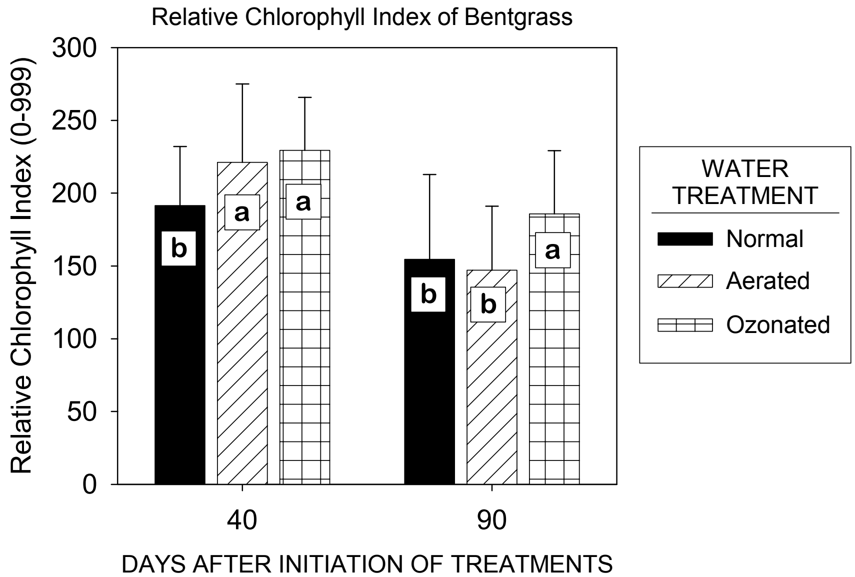


Fig. 4. Effect of water source on the relative chlorophyll index† of bentgrass 40 days and 90 days after initiating water treatments. For each sampling date, columns with the same letter are not significantly different (Duncan's MRT, $p \leq 0.05$). †Fieldscout CM1000 Chlorophyll meter, Spectrum Technologies, Inc., Plainfield, IL 60544

Bentgrass cores were clipped ten times in the 330 days following initiation of the water treatments. The length of time between clippings ranged from 19 to 75 days and depended on a variety of conditions including frequency of fertilization and watering as well as seasonal changes in greenhouse growing conditions. Aerated water significantly increased bentgrass clipping weights 103 days after initiating water treatments and the ozonated water treatment also tended to increase clipping weights for that sample date (Table 2). Increased clipping weight for the aerated treatment corresponded to increased N concentration in bentgrass tissue (Fig. 5). Ozonated water significantly increased bentgrass clipping weights 128 days after initiating water treatments (Table 2), but in this instance, there was no significant difference in bentgrass N concentration among the three treatments (Fig. 5).

The fact that ozonated and aerated water increased bentgrass clipping weights in late spring and early summer, but did not affect weights in early spring or late summer and early fall is probably related to seasonal variations in greenhouse growing conditions. Bentgrass growth was probably affected by short day lengths during the winter months and by high temperatures during summer months.

**Crown / root growth and soil organic matter:** Bentgrass crown weights were significantly increased by ozonated water at 70 and 274 days after initiation of water treatments (Fig. 6). However, water treatments had no significant effect on root mass at any of the sampling depths or times. Twelve months after initiating the study, there was no difference among treatments in soil organic matter content in the upper 1.5 inches of the bentgrass cores (Fig. 7). Raub et al. (2001) calculated that the ozone in ozonated water penetrated to a depth of <2 mm, indicating that the ozone-related reactions were limited to the soil surface. Therefore, it is likely that the ozone treated water in our study had its greatest effect in the crown area of the bentgrass cores and the roots immediately below the crown area. If roots from the top 0.5 inches of the bentgrass core had been separated from the deeper roots, perhaps we would have measured a significant difference at that depth.

Table 2. Effect of water treatments on bentgrass clipping weights at various times after initiation of treatments. Treatment means for a given date followed by the same letter are not significalty different (Fisher's LSD, p≤0.05).

| Date | DAIT† | DALFA‡ | Control | | Aerated | | Ozonated | |
|---|---|---|---|---|---|---|---|---|
| 2/14/02 | 28 | 14 | 0.48 | a | 0.49 | a | 0.47 | a |
| 4/30/02 | 103 | 40 | 1.61 | b | 1.85 | a | 1.79 | ab |
| 5/28/02 | 128 | 28 | 1.03 | b | 1.08 | b | 1.20 | a |
| 6/26/02 | 157 | 57 | 0.72 | b | 0.93 | a | 0.95 | a |
| 7/30/02 | 191 | 15 | 0.93 | a | 0.84 | a | 0.91 | a |
| 9/15/02 | 238 | 62 | 0.59 | a | 0.60 | a | 0.67 | a |
| 10/16/02 | 269 | 62 | 0.97 | a | 0.97 | a | 0.96 | a |
| 11/4/02 | 288 | 10 | 0.89 | a | 0.81 | a | 0.90 | a |
| 11/26/02 | 310 | 32 | 0.91 | a | 0.85 | a | 0.91 | a |
| 12/16/02 | 330 | 52 | 0.79 | a | 0.83 | a | 0.88 | a |

† Days after initiation of treatments.
‡ Days after last fertilizer application (1 lb N /1000 ft2 as $(NH_4)_2SO_4$

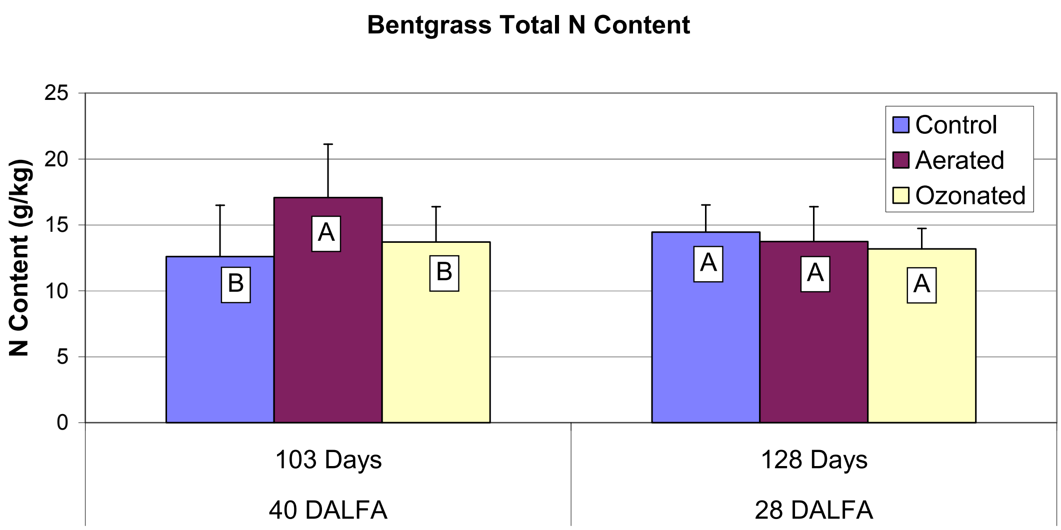


Fig. 5. Effect of water aeration and ozonation on total N content of bentgrass clippings 103 and 128 days after initiating water treatments, which also corresponded to 40 and 28 days after the most recent fertilizer application, respectively. For each sampling date, colums with the same letter are not significantly different (Fisher's LSD, p≤0.05).

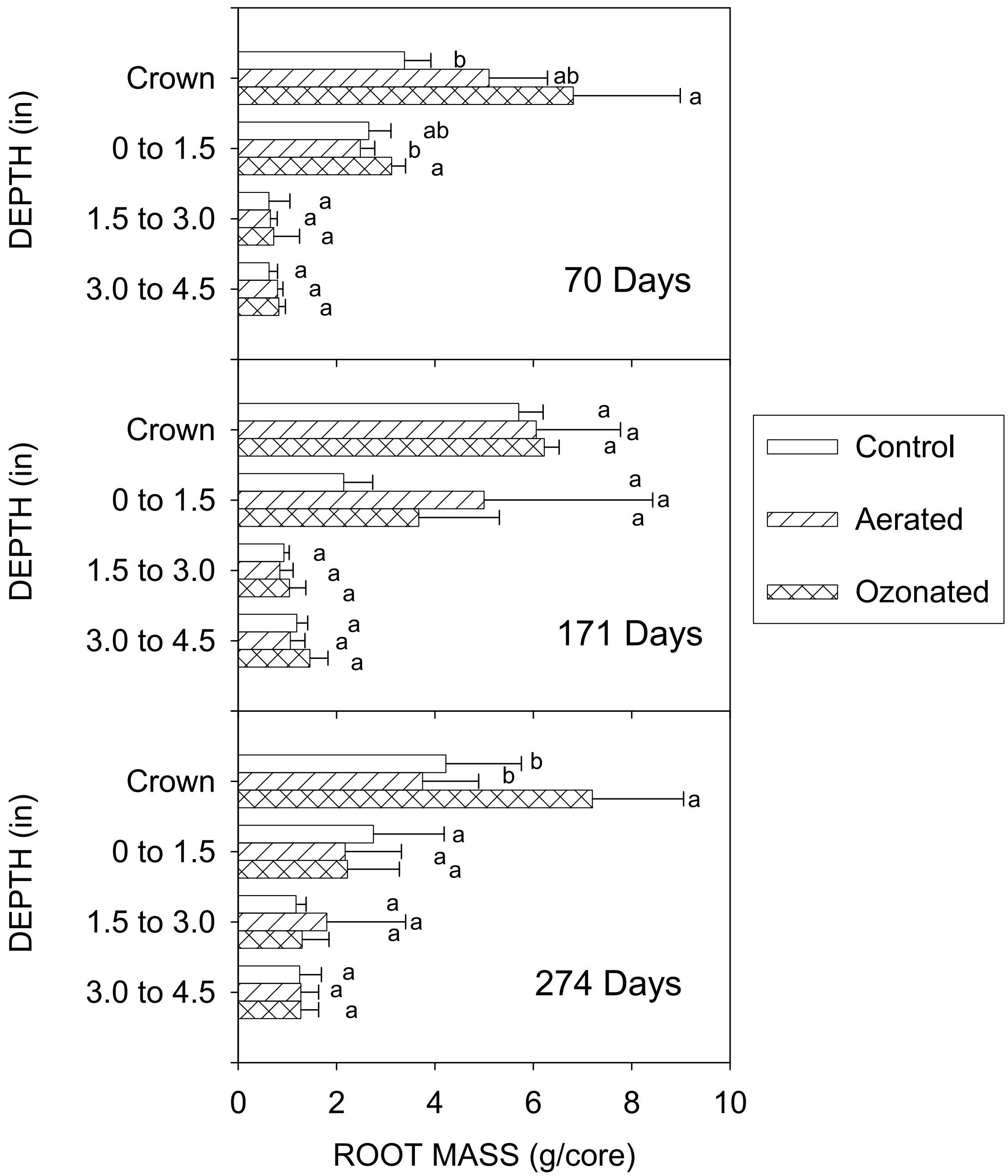


Fig. 6. Effect of water aeration and ozonation on bentgrass crown and root mass at 70, 171, and 274 days after initiation of water treatments. Columns for each sampling data and depth labeled with the same letter are not significantly different (Fisher's LSD, $p \leq 0.05$).

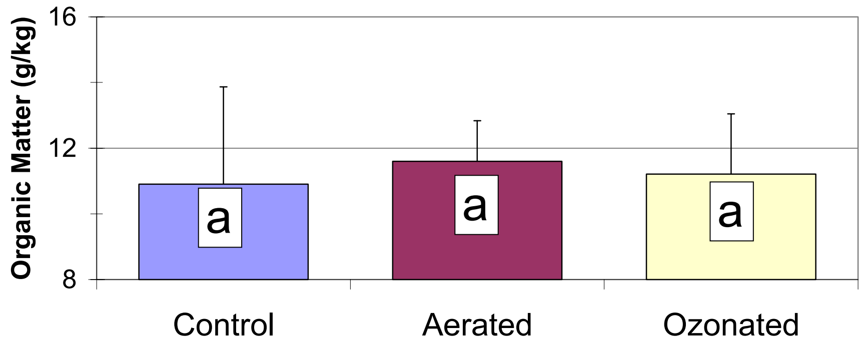


Fig. 7. Soil organic matter contents at 0-1.5 inches after 12 months irrigation with normal tap water, aerated water, or ozonated water. Columns with the same letter are not statistically different (Fisher's LSD, $p \leq 0.05$.

## CONCLUSIONS

A one-year study provided evidence that ozonated water had some beneficial effects on bentgrass growth, but the effects were not consistent during the entire length of the study. The clearest evidence was increased clipping weights and higher chlorophyll content of bentgrass treated with ozonated water. These effects corresponded to increased $NO_3$-N concentrations in leachate water, suggesting that improved growth was the result of increased nutrients released by the breakdown of organic residues. Some of these same effects were also apparent for aerated water. It is likely that the effects observed in this study would be more prominent with higher levels of ozone in the irrigation water.

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