# IRON FERTILIZATION EFFECTS ON CREEPING BENTGRASS SHOOT AND ROOT GROWTH[1]

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ABSTRACT

'Penncross' creeping bentgrass (Agrostis palustris Huds.) was grown in containers to evaluate the effect of various Fe fertilizers on shoot and root growth. Iron (Fe) had little effect on bentgrass color, density, and shoot growth rate. One source, Lawn-Plex, slightly improved turfgrass quality. Iron applications caused no change in total, bulk-soil root growth (mass or length). However, Fe fertilizers influenced root growth that occurred after the first Fe treatment. Chelated sources promoted root growth, while inorganic sources inhibited root growth. The increase in root growth associated with the chelated sources manifested itself mainly between 10-20 cm.

Most golfers prefer the speed, smoothness and prestige associated with creeping bentgrass (Agrostis palustris Huds.) golf greens. Unfortunately, most golf courses in the United States exist in climates warmer than ideal for bentgrass growth. The cool-season grass is best adapted to temperatures in the range of 15-24° C. As temperatures rise above this range, bentgrass undergoes various stages of heat and drought stress. The increase in popularity of bentgrass greens in the mid to northern areas of the Southeastern United States has increased the appearance of bentgrass heat and drought stress, and subsequently increased the need and interest in identifying managerial practices which may alleviate stress. Preliminary research by Snyder and Schmidt (15) and Schmidt and Snyder (18) indicate Fe fertilizers provide a possible means of alleviating some of this stress.

Bentgrass managers often incorporate Fe into fertility programs (18) to improve color (2 4 5 6 11 15 18 20). Iron may reduce the need for nitrogen (N) applications (20). Less N could reduce top growth and improve drought tolerance by decreasing succulent growth and total evapotranspiration (17). Another possible, more direct benefit of Fe on drought tolerance is increased root growth (6 15 18). Under certain conditions, Snyder and Schmidt (18) noted Fe increased root growth and improved winter desiccation recovery of bentgrass putting greens.

In this study we investigated the potential for various Fe carriers to influence root growth, and therefore influence drought and heat tolerance. In addition, the effects of Fe on bentgrass color, density, quality and growth rate were evaluated. 'Penncross' creeping bentgrass was grown in transparent polyethylene tubes [16.5 cm diam x 60 cm (McMaster-Carr Supply Company, Chicago, IL)] to determine the effect of various Fe fertilizers on shoot and root growth. The tubes contained a commonly used medium for golf course greens of 85% sand (88%=0.25-1.0 mm, 11%<0.25 mm) and 15% peat (by volume). Soil tests indicated pH, P and K were below Georgia Extension recommendations. Calcium hydroxide was added to increase pH to 6.5. Nutrient levels were increased to 42.6 kg $P \cdot ha^{-1}$ (medium) and 97.6 kg $K \cdot ha^{-1}$ (high) with $KH_2PO_4$ and KCl. Nitrogen was initially supplemented with $NH_4NO_3$ (24.4 kg $N \cdot ha^{-1}$). Measured Fe content indicated 30.7 kg $Fe \cdot ha^{-1}$ (double-acid extraction) (8).

After amendending soil, one end of the tubes was folded and sealed with staples and tubes were filled. Small volumes of soil were packed into the containers until all wrinkles were removed. All tubes were of equal volume. The approximate soil bulk density was 1.54 $g \cdot cm^{-1}$. After packing, tubes were set on an A-frame structure at 20° from vertical. To promote settling, tubes were fully saturated with water. Further wrinkles were removed by tamping; final soil heights varied (±2 cm) and were adjusted to equivalent levels.

On 15 Feb. 1987 'Penncross' creeping bentgrass plugs (17.8 cm diam x 10 cm) were cut from an experimental golf green at the University of Georgia Extension Turfgrass Plots in Athens, Georgia. Soil was washed from the plugs, after which all roots below the thatch-soil interface were removed. Plugs were fitted into the plastic tubes, firmly packed and watered. Each tube was wrapped in two layers of 0.1 mm, black plastic. A layer of plastic was also wrapped around the front of the A-frame which held the tubes.

Throughout the growing period (15 Feb.-26 Mar. 1987), greenhouse controls were set to maintain a temperature of 24° C. On several occasions temperature readings indicated night-time lows of 14.4°C and day-time highs of 39.4°C. On two occasions, soil temperatures were measured at several depths by inserting a thermometer through the plastic...soil temperatures corresponded with air temperatures. Fluorescent lights at 30 cm above the turfgrass surface supplemented natural lighting from 0600 to 1800 h.

During the growing period turfgrass was cut daily at heights between 3.1 and 6.3 mm. Water was applied as needed; all applications were sufficient to saturate a few centimeters below the deepest appearing roots of the tube containing the deepest roots. Actual application rates approximated 2.6 cm of water every other day. Nitrogen was applied monthly as urea with a total addition of 85 kg $N \cdot ha^{-1}$. To maintain contact between turfgrass and plastic, all tubes received three light topdressings.

One month after establishment, Fe fertilizers were applied (0700 h). The turf was cut and watered prior to application, 16 and 10 h, respectively. Iron treatments included a control and three Fe carriers: (a) iron sulfate (FS)--Fisher Analytical Reagent[1] $FeSO_4 \cdot 7H_2O$ (Fair Lawn, NJ), 20% Fe, 12% S; (b) Lawn-Plex (LP)--R.G.B Laboratories[1] Fe phosphate-citrate (Kansas City, MO), 8% Fe, 8% S; (c) Sequestrene 330 (Seq 330)--Ciba-Geigy[1] sodium ferric diethylenetriaminepentacetate (Greensboro, NC). Iron was applied at 1.12 kg $Fe \cdot ha^{-1}$. Applications were made with a spray bottle. Turf was re-cut 12 h and watered 31 h after application. The second Fe application occurred on 29 Apr. 1987 under similar managerial conditions as the first application.

Root measurements were made one day before and three days after the initial application. Trans-Art Trans-Stay Clear Polyester sheets (Transilwrap Company of Atlanta, Inc., Atlanta, GA) were taped to the back of each tube. Roots within a 10 cm band (width) were traced onto the sheets. Cooper et al. (3) reported bentgrass roots fluoresce with exposure to ultraviolet light (UV), thereby increasing their visibility. In this study root tracings

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[1] Mention of a product does not constitute endorsement or preference of the product over similar products.

occurred at night under UV light (320-400 nm)[2] generated by Model B-100A/R Black-Ray Ultra-Violet Lamp (UVP, Inc., San Gabriel, CA). Root tracings were made once a week, using permanent marking pens with different colors to distinguish dates. Root lengths were measured in 5 cm depth-intervals from the traced sheets with a LASICO Model 71A Linear Measuring Probe (Los Angeles Scientific Instrument Company, Los Angeles, CA).

Turfgrass quality and color were evaluated weekly. Quality was based on color, density, texture and uniformity (9=very high quality turf; 1=no live turf). Shoot color was evaluated with a Munsells Color Chart for Plant Tissue (Munsell Color, Baltimore Maryland). Color tiles were held directly behind pots, matching the color of the tile with the turf. Comparisons were made between numbers assigned to tiles (20=dark green turf, 1=no green turf).

Once a week relative turfgrass density was measured. Density was determined by randomly tossing a rubber ring (0.71 $cm^2$) onto recently cut turf, and counting the number of leaf tips within the ring. Three counts were made per tube.

Turf was cut daily with automatic clippers. On three occasions (12-18 Apr., 30 Apr.-6 May, 20-26 May) clippings

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[2] Several researchers (1 9 13) have found U.V. radiation influences foliar Fe status (reduces inactive $Fe^{3+}$ to active $Fe^{2+}$). Ultra-violet light may also influence soil and root Fe status. In such a case, the use of U.V. in this study may have influenced results.

were collected and dried at 70° C (24 h) in preparation for later weight comparisons.

On 26 May 1987 verdure was separated from the roots by cutting through the plastic immediately below crown level. Tubes were further divided into ten 5 cm segments (50 cm total depth). Cuts were made parallel to the original turfgrass surface. Roots were collected by hand sifting segments through an 1.0 mm screen (18 mesh). Roots were refrigerated (3.0° C) in plastic bags until 3 Aug. 1987, at which time root length was determined using the root intercept methods and Newman's equation (12). Due to the large volume of roots above 30 cm, four sub-samples were used to determine root lengths. After drying samples (70° C for 24 h), length of the bulk samples was interpolated from length and weight of the sub-samples.

Traced root length was evaluated by several methods: 1) Traced root length equaled the length of traced roots per unit of tracing area; 2) Traced root density (19) equalled the traced root length per volume of soil; soil volume equaled the tracing area x the depth at which roots could be seen (3mm)(19); and, 3) Traced root length per area of sod equaled the traced root length per area of sod directly above and to the up-viewing-plane side of the tracing depth. Since the traced root length per area of sod method most acucurately represented root distribution (7), discussion concentrates on results obtained from this technique. In addition to analyzing traced root length, final root weight and length (root intercept method and Newman's equation) were evaluated.

Iron normally improves turfgrass color under Fe-deficient (5 10 11 16) and Fe-sufficient conditions (2 15 18 20). In this study, although FS appeared to have a slight tendency to improve color and LP to lower color, Fe had insignificant influence on turfgrass color (Table 1). Time of application influences the ability of Fe to improve turfgrass color; in general, spring-early summer conditions hinder color improvement (15 18 20). Snyder and Schmidt (18) noted spring applications of Fe (FeDPTA and FS) on creeping bentgrass had little effect on turfgrass color. In spring, Schmidt (14) speculates soil temperatures optimize microbial activity and plant metabolism which stimulate Fe availability. Spring like conditions (temperatures, light levels, irrigation rates) in this study may have contributed to the lack of Fe response.

Levels of other nutrients also influences the ability of Fe to improve turfgrass color. Snyder and Schmidt (18) and Carrow et al. (2) found moderate to high N levels enhanced the effectiveness of Fe. Other researchers (5 20) have found Fe responses less detectable under high fertility programs. Since our study was conducted in a greenhouse, under 'optimal' growing conditions, existing healthy, green tissue may have masked an Fe responses.

The components of turfgrass visual quality are color, shoot density, leaf texture and sward uniformity. In the current study, Fe applications had minor effect on turfgrass quality (Table 2). Lawn-Plex briefly improved quality relative to FS--2, 12, and 26 days after the first applications. Likewise, one day after the second Fe application (28 Apr.), quality of LP was superior to FS and equivalent to Seq 330 and the control. Although not significantly different, FS treatments tended to have lower visual quality than the control. At the 10% level (data not shown), 58% of the FS quality ratings showed inferior quality to LP treatments. Carrow et al. (2) found Fe enhanced visual quality of centipedegrass (Eremochloa ophiuoides [Munro] Hack.); Fe source (FS, ferrous ammonium sulfate and Seq 330) had no effect on magnitude or duration of response. Schmidt (14) reported FeDTPA increased Kentucky bluegrass (Poa pratensis L.) density, which could relate to changes in visual quality. Deal and Engel (5) noted an increase in Kentucky bluegrass density associated with Fe and low fertility levels.

The reasons for superior quality of the LP treatments remain unclear. Slight tendencies for increased density (Table 3) could have contributed to LP's higher quality. However, increased density appeared after increased quality (Tables 2 and 3). Also, components of turfgrass quality such as color uniformity and shoot texture which were not individually evaluated may have contributed to slightly higher quality for LP.

Iron applications had little effect on clipping yields (Table 4). During the last collection period (20 to 26 May), LP treatments had less growth than FS. Other studies indicate Fe may or may not influence turfgrass growth rates. Horst (6) reported Fe increased the top growth of establishing bermudagrass. Under Fe-sufficient conditions, Snyder and Schmidt (18), and Schmidt and Snyder (15) reported Fe applications increased bentgrass top growth during cool seasons, and decreased top growth as temperature increased. Other studies (2 5 20) have found Fe had no effect on top growth (Kentucky bluegrass and centipedegrass).

Iron fertilization affected the amount of root growth that occurred after the first Fe application (Table 5). Both Seq 330 and LP produced 27% more total root length per unit area of sod than FS. Although not significant, Seq 330 and LP produced 22% more root length than the control. By depth, LP and Seq 330 produced more roots between 10-15 cm than FS and the control. At 15-20 cm, LP treatments possessed more roots than FS, while at 30-35 cm they produced more roots than FS and Seq 330.

Root growth that occurred between tracings differed on one measuring date (12 Apr.), 13 days after the first Fe application (Table 6). Seq 330 produced more roots than FS. Root analysis by date indicated Seq 330 and LP tended to generate more root growth than FS and the control.

New root growth appeared to emerge as downward extensions of existing roots. The majority of new growth occurred between the bottom half to quarter of existing root systems. Comparing time of Fe application to new root growth by depth and date (Table 5 and 6), it appears Fe impacts the lower portion of the existing root system, about two weeks after application. Thirteen days after the initial Fe application, Seq 330 had more total growth than FS. Although no other significant differences occurred by date, similar trends appeared: 19 days after the second Fe application, Lawn-plex and Seq 330 produced more growth than the control, while FS produced less. Total new root growth from 2 Apr. to 24 May reflected a positive LP and Seq 330 response.

Using the tracing technique, Fe applications affected total root growth (Table 6). Seq 330 produced 15% more root length than the control. Although not statistically significant, LP and FS yielded 10% more growth than the control. However, the results for FS may be misleading due to large initial growth before Fe applications.

Although Fe applications affected total root growth according to the tracing technique, they had no effect on total harvested root mass or length (Table 7). Although not significant, Seq 330 seemed to increase and FS decrease total root growth. Seq 330 and the control had root masses approximately 8 and 15% greater than LP and FS, respectively. Seq 330 produced 18, 21, and 26% more root length than the control, LP, and FS, respectively. Also, LP seemed to alter root morphology: analysis of root length per root mass suggests LP either decreased root width or density.

Several researchers have reported increased root mass associated with Fe applications (5 6 18). Horst (6) reported applications of Fe increased root growth of establishing bermudagrass. Deal and Engel (5) noted Fe increased root mass of Kentucky bluegrass. On creeping bentgrass putting greens, Snyder and Schmidt (18) found fall-winter (Oct. and Nov., or Oct., Nov. and Dec.) Fe applications increased spring root weight compared to treatments receiving a single application of N in Oct. Spring (May-June) applications of Fe + N increased July root weight (relative to low N, high N or low Fe + N). Also, they found increased frequency of Fe applications (fall-winter) tended to increase root growth (measured in July) under two N regimes (late fall or early spring). In a follow-up investigation, under greenhouse conditions, Schmidt and Snyder (15) investigated the effects of Fe on bentgrass growth and physiology. They noted a tendency for Seq 330 to increase root growth.

Under conditions of the present study, applications of Fe had minor influences on bentgrass shoots--color, density, and growth rate. Lawn-Plex tended to promote quality and density, while FS tended to decrease quality. Iron sources did effect root growth with chelated sources

(LP and Seq 330) tending to increase root growth, particulary between 10-20 cm. The inorganic source (FS) tended to decrease growth. Since Fe sources differed in response, the effects may be from an Fe carrier influence as much as Fe. This suggests that in Fe studies the carrier influence may cause some of the root growth responses attributed to Fe. Also, results based on root weights may not be extrapolated to indicate length responses. The rooting responses observed for LP and Seq 330 indicate they may contribute to better drought and heat tolerance of bentgrass.

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Table 1. Color response of bentgrass to various Fe fertilizers while maintained as a golf green under greenhouse conditions.

| Date | Fe Carrier[z] | | | |
|---|---|---|---|---|
| | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | 20=dark green, 1=no green | | | |
| 29 Mar. | 8.0a[y] | 7.0a | 7.0a | 11.0a |
| 2 Apr.[x] | 11.7a | 12.3a | 11.7a | 13.3a |
| 5 | 7.0ab | 10.7a | 7.0ab | 4.7b |
| 12 | 7.0b | 15.0a | 10.7ab | 7.7b |
| 19 | 4.0a | 4.3a | 6.3a | 6.0a |
| 26 | 13.0a | 13.0a | 12.3a | 9.3a |
| 29[x] | 12.3a | 16.0a | 16.0a | 12.7a |
| 3 May | 11.7a | 11.0a | 12.3a | 11.7a |
| 9 | 14.7a | 15.3a | 16.7a | 10.3a[w] |
| 17 | 3.7a | 3.3a | 6.7a | 6.0a |
| 24 | 12.7a | 5.0b[v] | 12.0a | 10.7a |

z Fe applied at 1.12 kg $Fe \cdot ha^{-1}$.
y Numbers in the same row followed by different letters indicate significant difference at 0.10 level (Duncan's Multiple Range Test).
x Fe applied 30 May and 28 Apr.
w Insect damage appeared in one of $FeSO_4$ replications, and probably influenced results.
v One replication showed moderate wilt on 10 May, so it was replaced by the average of other replications.

Table 2. Visual quality[v] reponse of bentgrass to various Fe fertilizers while maintained as a golf green under greenhouse conditions.

| Date | Fe Carrier[z] | | | |
|---|---|---|---|---|
| | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | 9=ideal visual quality; 1=no live turf | | | |
| 29 Mar. | 7.7a[y] | 7.2a | 7.3a | 7.4a |
| 2 Apr.[x] | 7.5ab | 7.2b | 7.6ab | 7.8a |
| 5 | 7.8a | 7.3a | 7.7a | 7.7a |
| 12 | 8.8a | 8.5b | 8.7ab | 8.9a |
| 19 | 8.3a | 7.9a | 8.2a | 8.3a |
| 26 | 8.7ab | 8.6b | 8.9a | 8.9a |
| 29[x] | 8.8ab | 8.6b | 8.7ab | 8.9a |
| 3 May | 8.7a | 8.4a | 8.6a | 8.7a |
| 9 | 7.5a | 6.6b | 7.7a | 7.8a[w] |
| 17 | 7.9a | 6.5b | 7.9a | 7.9a |
| 24 | 7.5ab | 6.9b | 7.7a | 7.8a |
| 28 | 7.8a | 7.9a | 7.8a | 7.8a |

y Fe applied at 1.12 kg $Fe \cdot ha^{-1}$.
z Numbers in the same row followed by different letters indicate significant difference at the 0.10 level (Duncan's Multiple Range Test).
x Fe applied 30 May and 28 Apr.
w One replication showed moderate wilt on 10 May.
v Visual quality consists of shoot density, color texture, and uniformity.

Table 3. Shoot density reponse of bentgrass to various Fe fertilizers while maintained under greenhouse conditions.

| Date | Fe Carrier[z] | | | |
|---|---|---|---|---|
| | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | leaf tips·$cm^{-2}$ | | | |
| 29 Mar. | 24.0b[y] | 27.6a | 25.5ab | 26.1ab |
| 2 Apr.[x] | 26.7a | 29.0a | 25.6a | 26.9a |
| 8 | 31.8b | 32.2b | 34.1a | 31.8b |
| 16 | 30.3b | 34.0a | 33.4ab | 31.4ab |
| 24 | 38.9ab | 37.8ab | 37.4b | 42.5a |
| 2 Apr.[x] | 37.5ab | 35.5b | 36.7ab | 41.3a |
| 8 | 38.4a | 38.0a | 37.2a | 37.8a |
| 15 | 36.1ab | 35.0ab | 34.8b | 41.0a |
| 22 | 34.9a | 36.2a | 36.6a | 35.8a |
| 28 | 31.0ab | 29.2b[w] | 32.2a | 32.1a |

z Fe applied at 1.12 kg Fe·$ha^{-1}$.
y Numbers in the same row followed by different letters indicate significant difference at the 0.10 level (Duncan's Multiple Range Test).
x Fe applied 30 May and 28 Apr.
w Insect damage appeared in one of FS replications, so it was replaced by average of other replications.

Table 4. Shoot growth reponse of bentgrass to various Fe fertilizers while maintained under greenhouse conditions.

| Date | Fe Carrier[z] | | | |
|---|---|---|---|---|
| | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | $g \cdot m^2$ | | | |
| 12 Apr.- 18 Apr. | 18.5a[y] | 19.8a | 20.6a | 18.2a |
| 30 Apr.- 6 May | 6.2a | 3.4a | 3.7a | 5.7a |
| 20 May - 26 May | 2.9ab | 5.2a | 4.4ab | 2.0bc |

z Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ on 29 Mar. and 28 Apr.
y numbers in the same row followed by different letters indicate significant difference at 0.10 level (Duncan's Multiple Range Test).

Table 5. Root growth response of bentgrass to various Fe fertilizers while maintained as a golf green under greenhouse conditions: root growth by depth that occurred from initial Fe application to study termination.

| | Fe Carrier[z] | | | |
|---|---|---|---|---|
| Depth (cm) | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | | cm | | |
| 0-5 | 46.9a[y] | 47.0a | 68.1a | 65.2a |
| 5-10 | 30.8a | 27.8a | 34.1a | 32.2a |
| 10-15 | 14.1b | 14.5b | 22.6a | 19.4a |
| 15-20 | 12.5ab | 11.0b | 14.6ab | 16.3a |
| 20-25 | 10.0a | 10.9a | 11.8a | 15.8a |
| 25-30 | 9.0a | 5.8a | 10.1a | 13.1a |
| 30-35 | 5.4ab | 3.0b | 4.7b | 7.4a |
| 35-40 | 2.0a | 3.1a | 2.4a | 2.6a |
| 40-45 | 2.4a | 0.5a | 3.0a | 0.4a |
| 45-50 | 0.2a | 0.2a | 0.2a | 0.4a |
| Total | 133.3ab | 123.9b | 171.7a | 172.8a |

z Fe applied at 1.12 kg $Fe \cdot ha^{-1}$ on 29 Mar. and 28 Apr.
y Means within a row with different letters are significantly different at the 0.05 level (Duncan's Multiple Range Test).

Table 6. Root growth response of bentgrass to various Fe fertilizers while maintained as a golf green under greenhouse conditions: total root growth that occurred between measurement dates.

| | Fe Carrier[z] | | | |
|---|---|---|---|---|
| Date | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| | cm of root·cm$^{-2}$ of sod | | | |
| 29 Mar. | 264.2a[y] | 315.8a | 297.6a | 264.7a |
| 2 Apr.[x] | 23.1a | 24.0a | 27.3a | 25.8a |
| 5 | 23.5a | 23.0a | 30.5a | 27.3a |
| 12 | 25.9ab | 19.5b | 33.9a | 26.7ab |
| 19 | 23.0a | 21.9a | 27.4a | 27.7a |
| 26 | 10.3a | 8.4a | 11.1a | 21.8a |
| 3 May[x] | 8.2a | 7.7a | 10.8a | 13.4a |
| 10 | 5.9a | 8.0a | 11.5a | 11.4a |
| 17 | 6.2a | 5.3a | 8.8a | 9.7a |
| 24 | 7.1a | 6.0a | 10.3a | 9.0a |
| Total | 397.3b | 439.6ab | 469.2a | 437.5ab |

z Fe applied at 1.12 kg Fe·ha$^{-1}$.
y Means within a row with different letters are significantly different at the 0.05 level (Duncan's Multiple Range Test).
x Fe applied 30 May and 28 April.

Table 7. Root growth response of bentgrass to various Fe fertilizers while maintained as a golf green under greenhouse conditions: total root that occurred from planting to study termination.

| | Fe Carrier[z] | | | |
|---|---|---|---|---|
| Root Growth | Control | $FeSO_4$ | Seq 330 | Lawn-Plex |
| Total root mass[y] | 5.66a[x] | 4.83a | 5.78a | 5.26a |
| Total root length density[w] | 5.01a | 4.54a | 6.13a | 4.87a |
| Root length per root mass (m·g) | 442a | 470a | 463a | 530a |

z Fe applied at 1.12 kg Fe·$ha^{-1}$.
y Mg of root per $cm^2$ of sod.
x Means within a row with different letters are significantly different at the 0.05 level (Duncan's Multiple Range Test).
w Cm of root (determined by root intercept method and Newman's equation) per $cm^3$ of soil.