Foliar Fertilization by Tank-mixing with Organic Amendment on Creeping Bentgrass

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ADDITIONAL INDEX WORDS. **fertigation, liquid fertilizer**

SUMMARY. **Foliar application of fertilizers on turfgrass via overhead fertigation or spray can improve nutrient absorption efficiency and uniformity. Foliar fertilizers can also be combined with other chemical applications to save labor and energy. However, foliar application of nitrogen may result in root growth reduction. The objective of this study was to evaluate if a liquid organic amendment can be tank-mixed with liquid fertilizer to improve creeping bentgrass (*Agrostis stolonifera*) performance. This greenhouse study was conducted on 'Penncross' creeping bentgrass grown in sand or 90 sand:10 peat (v/v) root zones. Three fertilizer packages (4N–0P–0.8K, 29N–0.9P–2.5K, and 20N–8.8P–16.6K) with or without the organic amendment, a liquid suspension derived from naturally mined humic materials, were tested in the study. Tank-mixing organic amendment resulted in better or same turfgrass visual quality and lower clipping yield compared with foliar fertilization alone. Tank-mixing organic amendment in liquid fertilizers resulted in an average increase of root/shoot biomass ratio from 0.62 to 0.65 grown in the sand-based root zones. The effect of organic amendment was shown in all liquid fertilizers tested except 20N–8.8P–16.6K. The results showed tank-mixing organic amendment with the right liquid fertilizer can reduce mowing frequency without reducing the turf quality. Field work is needed to test if the increased root/shoot biomass ratio by tank-mixing organic amendment with liquid fertilizer can contribute to drought tolerance in creeping bentgrass maintained at fairway height in sand-based root zones.**

Fertilizers are commonly applied to turfgrass episodically, which usually causes a surge of absorption and growth intermittent with different degrees of deficiencies (Stiegler et al., 2011). In turfgrass management, yield is not the primary purpose of fertilization; rather stable color, vigor, and recuperation from damage are the goals of a fertilization program (Yust et al., 1984). To maintain constant turf qualities, slow-release fertilizers and different technologies, such as spoon-feeding program that relies on frequent and low-rate application, are used to simulate the natural mineralization in providing nutrients to turfgrasses at a regulated speed with high fertilizer use efficacy and low application cost (Spangenberg et al., 1986). Foliar application is one of those technologies, which was heavily investigated in the late 1940s and early 1950s (Fritz, 1978; Haq and Mallarino, 2000).

Compared with soil applied fertilizers, foliar applied fertilizers correct nutrient deficiencies faster, provide soil-immobile nutrients more efficiently, and reduce nutrient losses because of denitrification and leaching (Fageria et al., 2009). Micronutrients that are required in small amounts can be applied more uniformly in spray than in granular forms to soils. Additionally, spraying fertilizer along with other chemicals as a tank-mix allows for reduction in labor, machinery, and energy. However, foliar application requires repeated applications, especially macronutrients, to meet the demand of plants. Wind can affect uniformity of foliar application.

Foliar fertigation, fertilization through the irrigation system, was found as effective as soil application on bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) (Snyder and Burt, 1976). In perennial ryegrass (*Lolium perenne*), daily foliar nitrogen (N) application resulted in increased shoot growth and decreased root biomass and length (Bowman, 2003). In creeping bentgrass, foliar N application provided better visual quality than granular fertilizers as reported by Steinke and Stier (2003). However, the results of foliar fertilization were not consistent in the study by Guertal (2010) and Stiegler et al. (2011). Zhang et al. (2003a) reported that applying seaweed extracts or humic acid together with liquid fertilizer did not improve the creeping bentgrass turf quality compared with fertilizer alone. However, addition of stimulants to fertilizer reduced dollar spot (*Sclerotinia homoeocarpa*) incidence during the summer because of improved plant health as reflected by the increase of antioxidants in treated plants.

Fernandez and Eichert (2009) provided a thorough review of the factors affecting the efficacy of foliar fertilizer application including the use of adjuvants. An adjuvant is a substance that is added to the spray tank to modify the activity of a.i. or spray characteristics and is one of the major technologies used to improve foliar fertilizer uptake (Hazen, 2000). Adding humectants to slow down drying process of foliar-applied chemicals has been reported effective in improving the performance of foliar nutrient application, especially in dry environments (Schonherr et al., 2005).

The results of foliar fertilization on creeping bentgrass are not consistent because of various environmental conditions, mowing height, nutrient forms, and addition of adjuvants. Many biostimulants such as humic substances are used by turfgrass managers either alone or in combination with tank-mixes of other chemicals (Karnok, 2000). Some of these humic substances also function as adjuvants (McWhorter et al., 1987). Since biostimulants are

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
9.3540	gal/acre	$L \cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	micron	μm	1
305.1517	oz/ft^2	$g \cdot m^{-2}$	0.0033
1	ppm	$mg \cdot kg^{-1}$	1
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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typically applied by spraying, their mixability with other foliar applications, such as liquid fertilizer, herbicides, and fungicides, is useful information for turfgrass managers. Rev™ (Dakota Peat, Grand Forks, ND) is a new organic amendment that is derived from naturally mined humic materials. The objective of this study was to investigate if the organic amendment sprayed tank-mixed with different N fertilizers affects fertilizer efficacy and turf quality.

Materials and methods

The study was conducted in 2011 in a greenhouse with temperature ranging from 15 °C (night) to 30 °C (day), relative humidity ranged from 5% to 40%, and 12-h photoperiod was supplemented to natural light by metal halide lamps that provided minimum midday photosynthetically active radiation of 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$. 'Penncross' creeping bentgrass was seeded at a rate of 50 $kg \cdot ha^{-1}$ in square plastic containers (6 × 6 × 6 inches) containing two different root-zone mediums. The first root-zone medium was sand with particle size conforming to the U.S. Golf Association (1993) specifications, 0.1% organic matter (OM), and pH of 7.6. The second root-zone medium was a mixture of 90% the same sand and 10% peat (v/v) (Dakota Peat, Grand Forks, ND), translating to 1% OM and pH 6.8. At the time of seeding and 4 weeks after, fertilizer was applied at a rate of 25 $kg \cdot ha^{-1}$ N from 5N–4.4P–4.2K liquid fertilizer (APT5M2X250; The Andersons, Maumee, OH). The root zones were kept moist for seed germination by watering twice daily. Once seeds germinated, the pots were watered from the top daily to field capacity based on the weight loss of the pots and the grasses were cut at 1-cm height weekly.

The fertilization treatments were initiated 8 weeks after germination. Three liquid fertilizers, 4N–0P–0.8K (Cytozorb-S, The Andersons), 29N–0.9P–2.5K (Nusion, The Andersons), and 20N–8.8P–16.6K (Jack's All Purpose; J.R. Peters, Allentown, PA) with or without adding organic amendment by tank-mix constituted six treatments (Table 1). The organic amendment is a liquid suspension derived from naturally mined humic materials with pH 6.2, 92 $mg \cdot kg^{-1}$ nitrate N, 5.3 $mg \cdot kg^{-1}$ ammoniacal N, 4 $mg \cdot kg^{-1}$ phosphorus (P), and 10 $mg \cdot kg^{-1}$ potassium (K). The material had particle sizes smaller than 100 µm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight. The liquid organic amendment was added

Table 1. Chemical analysis and application rates of the fertilizers used alone or tank-mixed with an organic amendment as foliar application on 'Penncross' creeping bentgrass. Liquid fertilizers (4N–0P–0.8K, 29N–0.9P–0.5K, and 20N–8.8P–16.6K) were applied at 12.21 $kg \cdot ha^{-1}$ nitrogen at 2-week intervals. Granular fertilizer (6N–0.9P–0K) was applied at 24.5 $kg \cdot ha^{-1}$ nitrogen at 4-week intervals. Organic amendment was added in spray solution at 3% (v/v).[z]

	Application rate ($kg \cdot ha^{-1}$)[z]		
Treatment	Nitrogen	Phosphorus	Potassium
4N–0P–0.8K[y]	12.21	0	3.02
29N–0.9P–0.5K[x]	12.21	0.84	1.26
20N–8.8P–16.6K[w]	12.21	12.21	12.21
4N–0P–0.8K + organic amendment[v]	12.21	0	3.02
29N–0.9P–0.5K + organic amendment	12.21	0.84	1.26
20N–8.8P–16.6K + organic amendment	12.21	12.21	12.21
6N–0.9P–0K[u]	24.50	9.93	0.00

[z]1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre.
[y]Cytozorb-S (APT4M2X25; The Andersons, Maumee, OH) contains 4.00% nitrogen (N) from nitrate, 0.83% potassium (K) from potassium nitrate, 0.53% magnesium (Mg), 1% sulfur (S) from combined sulfur, 2% iron (Fe), 0.25% manganese (Mn), and 0.20% zinc (Zn).
[x]Nusion (APT2922X25, The Andersons) contains 29% total N (8.12% urea N, 20.88% other water-soluble slowly available N from urea-triazone solution), 0.88% phosphorus (P) from potassium polyphosphate, and 2.4% K from potassium polyphosphate.
[w]Jack's All Purpose (J.R. Peters, Allentown, PA) contains 20% total N (3.83% ammoniacal N, 6.07% nitrate N, 10.10% urea N), 8.8% available P from ammonia phosphate, 16.6% K from potassium nitrate, 0.05% Mg from magnesium sulfate, 0.0068% boron (B) from boric acid, 0.0009% molybdenum (Mo) from ammonium molybdate, 0.0036% chelated copper (Cu), 0.0500% chelated Fe, 0.0250% chelated Mn, and 0.0025% chelated Zn. All chelations are from ethylenediaminetetraacetic acid (EDTA).
[v]Rev™ (Dakota Peat, Grand Forks, ND) is derived from naturally mined humic materials with pH 6.2, 9.2 $mg \cdot kg^{-1}$ nitrate N, 5.3 $mg \cdot kg^{-1}$ ammoniacal N, 4 $mg \cdot kg^{-1}$ P, and 10 $mg \cdot kg^{-1}$ K. The material had particle sizes smaller than 100 µm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight; 1 $mg \cdot kg^{-1}$ = 1 ppm, 1 µm = 1 micron.
[u]Milorganite (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) contains 6% total N (0.5% water-soluble N, 5.5% slow-release N), 0.88% P, and 4.0% Fe.

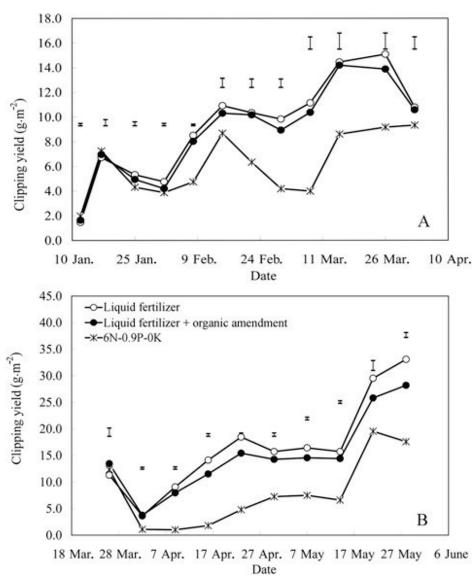

Fig. 1. Adding liquid organic amendment (Rev™; Dakota Peat, Grand Forks, ND) in spray solution at 3% (v/v) to liquid fertilizer [4N–0P–0.8K (Cytozorb-S; The Andersons, Maumee, OH), 29N–0.9P–2.5K (Nusion, The Andersons), and 20N–8.8P–16.6K (Jack's All Purpose; J.R. Peters, Allentown, PA)] in tank-mix resulted in less clipping yield in 'Penncross' creeping bentgrass. Granular 6N–0.9P–0K organic fertilizer (Milorganite; Milwaukee Metropolitan Sewerage District, Milwaukee, WI) was included as a reference. Liquid fertilizers were applied at 12.21 $kg \cdot ha^{-1}$ (10.894 lb/acre) N at 2-week intervals. Granular fertilizer was applied at 24.5 $kg \cdot ha^{-1}$ (21.86 lb/acre) N at 4-week intervals. Vertical bars represent least significant difference value at 0.05 *P* level. The results were shown for (A) study one and (B) study two; 1 $g \cdot m^{-2}$ = 0.0033 oz/ft².

to the spray solution at 3% (v/v) of the total volume. All liquid fertilizers were dissolved into water before adding organic amendment and brought to final volume before spraying. The foliar application was delivered with a carbon dioxide (CO_2)-pressurized sprayer at 250 kPa and equipped with a flood nozzle (TeeJet 8004VS; Spray Systems, Springfield, IL) to deliver a spray volume of 750 $L \cdot ha^{-1}$. All liquid fertilizers, except 4N–0P–0.8K, were applied at 12.21 $kg \cdot ha^{-1}$ N at 2-week intervals based on the manufacturer's recommendation. The 4N–0P–0.8K was applied daily at 0.87 $kg \cdot ha^{-1}$ N following the manufacturer's recommendation to avoid leaf burning. The contribution of organic amendment to total N, P, and K in spray solution was less than 0.002%. A 6N–0.9P–0K organic granular fertilizer (Milorganite; Milwaukee Metropolitan Sewerage District, Milwaukee, WI) applied every 4 weeks at 24.5 $kg \cdot ha^{-1}$ N was included in the study as a reference.

The treatments in the first study were initiated on 12 Jan. 2011, and the treatments in the second study were initiated on 20 Mar. 2011. After the 8-week fertilization period, a 4-week no-fertilization period was introduced to evaluate the fertility levels remaining in the root zones based on clipping yield change and visual quality. After the evaluation, watering was ceased to introduce a drought stress on the grass to test the effect of foliar fertilization on drought tolerance.

At the beginning of the fertilization treatment, and 2 weeks thereafter, an image was taken from each pot under natural light using a digital camera (Power Shot G3; Canon, Tokyo, Japan) with settings of F2.0 and 1/60 s. The digital pictures were then analyzed using the software package NIH Image 1.45i (National Institutes of Health, Bethesda, MD). Turfgrass green density and dark green color index (DGCI) were calculated following the methods of Richardson et al. (2001) and Karcher and Richardson (2003, 2005). At the time of digital image collection, the reflectance spectrum from 350 to 1000 nm was collected with a temperature-regulated fiber optic spectrometer (S2000-TR; Ocean Optics, Dunedin, FL), which has a fiber optic cable connected to a lens allowing a view field the size of the turfgrass surface in the pot. A modified normalized difference (mND) vegetation index $mND_{750/705}$ (Sims and Gamon, 2002) was calculated from the relative reflective spectra using the equation: $mND_{750/705} = (R_{750} - R_{705})/(R_{750}+R_{705} - 2R_{445})$, where R is the relative reflectance at a given wavelength.

Clipping and visual quality were evaluated weekly after the initiation of fertilization treatment. Visual quality was based on a 1–9 scale, where 1 was dead grass, 9 was the best, and 6 was the minimum acceptable level. Dry clipping yield was derived after drying the harvested clippings in an oven at 68 °C for 48 h. The date of wilting appearance after the last time of watering was recorded as an indicator of drought-stress avoidance. At the end of the drought period, the biomass above soil surface was harvested as shoot, and the roots were washed free of sand. The shoot and root biomass were derived after drying in an oven at 68 °C for 48 h.

The study was a split-plot design with root-zone medium as the main plot and fertilizer types as the subplot.

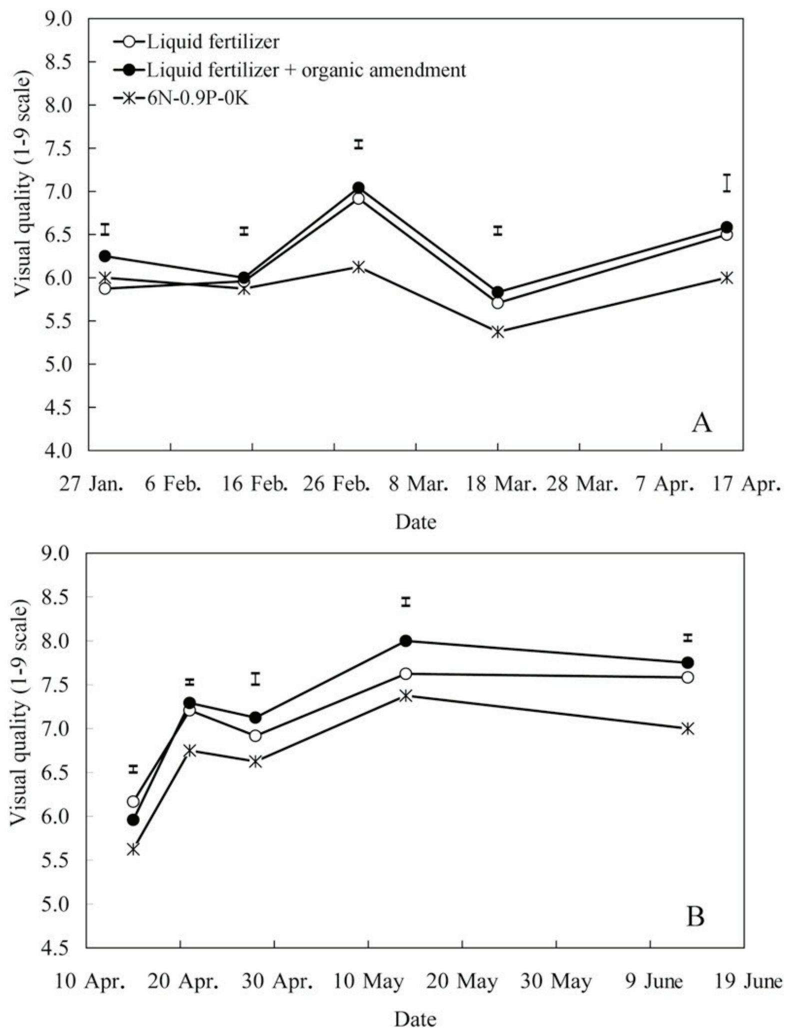

Fig. 2. Adding liquid organic amendment (Rev™; Dakota Peat, Grand Forks, ND) in spray solution at 3% (v/v) to liquid fertilizer [4N–0P–0.8K (Cytozorb-S; The Andersons, Maumee, OH), 29N–0.9P–2.5K (Nusion, The Andersons), and 20N–8.8P–16.6K (Jack's All Purpose; J.R. Peters, Allentown, PA)] in tank-mix resulted in equal or better visual turf quality in 'Penncross' creeping bentgrass. Visual quality was based on a 1–9 scale, where 1 was dead grass, 9 was the best, and 6 was the minimum acceptable level. Granular 6N–0.9P–0K organic fertilizer (Milorganite; Milwaukee Metropolitan Sewerage District, Milwaukee, WI) was included as a reference. Liquid fertilizers were applied at 12.21 $kg \cdot ha^{-1}$ (10.894 lb/acre) N at 2-week intervals. Granular fertilizer was applied at 24.5 $kg \cdot ha^{-1}$ (21.86 lb/acre) N at 4-week intervals. Vertical bars represent least significant difference value at 0.05 P level. The results were shown for (A) study one and (B) study two.

The study was repeated once with similar schedules for treatment applications and measurements. The data were subjected to analysis of variance (ANOVA) using mixed procedures in SAS (version 9.2; SAS Institute, Cary, NC) with replication blocks treated as a random variable. Treatment means were separated using Fisher's protected least significant difference at 0.05 *P* level. The means of foliar fertilizations with and without the organic amendment were compared using predesigned contrast.

Results and discussion

The ANOVA showed interactions between the study and treatments for the clipping yield, visual and imagery quality. Therefore, the results are reported separately by study. The results of biomass, root/shoot dry biomass ratio, and drought tolerance from the two studies were of homogenous variability without interactions. Those data are presented with two studies combined.

The average clipping yield was generally lower in foliar fertilization treatments with the organic amendment in tank-mix than in foliar fertilization without the amendment (Fig. 1), with the decrease up to 8% in the first study and up to 15% in the second study. The difference was significant in 2 of 12 measurements in the first study and 8 of 12 measurements in the second study (Fig. 1). The visual quality of the foliar fertilization treatments with the organic amendment in tank-mix was generally higher than the treatments without the amendment (Fig. 2). Clipping yield and visual quality in foliar fertilization treatments were higher than the granular 6N–0.9P–0K fertilization treatment starting at 2 weeks after the initiation in the first study and 1 week after the initiation in the second study (Figs. 1 and 2).

Addition of organic amendment did not result in any differences in *mND* values except for the 29N–0.9P–2.5K treatment in the second study (Tables 2 and 3). Only at 12 weeks after initiation of treatments in the second study, did addition of the organic amendment result in increased *mND* for 4N–0P–0.8K and 20N–8.8P–16.6K. Stiegler et al. (2005) also reported that normalized difference vegetation index did not reflect pigment content in creeping bentgrass. Similarly, adding organic amendment did not result in any differences in DGCI values except for the 20N–8.8P–16.6K in the second study (Tables 2 and 3). Overall, addition of the organic amendment resulted in increase in green density three of four measurements (Tables 2 and 3). The results from digital analysis confirmed the visual evaluation. However, despite the statistical significance, the small improvement in *mND* or DGCI may not be of practical value.

Tank-mixing the organic amendment in liquid fertilizers resulted in an increase of root/shoot biomass ratio of 'Penncross' creeping bentgrass grown in the sand-based root zones

Table 2. Imagery quality of 'Penncross' creeping bentgrass as affected by foliar application of fertilizers and tank-mix with liquid organic amendment in the first study of 2011. Liquid fertilizers (4N–0P–0.8K, 29N–0.9P–0.5K, and 20N–8.8P–16.6K) were applied at 12.21 kg·ha⁻¹ (10.894 lb/acre) nitrogen at 2-week intervals. Granular fertilizer (6N–0.9P–0K) was applied at 24.5 kg·ha⁻¹ (21.86 lb/acre) nitrogen at 4-week intervals. Organic amendment was added in spray solution at 3% (v/v).

	29 Jan. 2011			18 Mar. 2011			15 Apr. 2011		
Treatment	*mND*[z]	DGCI[y]	Green density (%)[x]	*mND*	DGCI	Green density (%)	*mND*	DGCI	Green density (%)
4N–0P–0.8K[w]	0.51	0.70	97.5	0.54	0.74	96.9	0.41	0.62	85.2
29N–0.9P–2.5K[v]	0.53	0.75	96.9	0.55	0.78	95.0	0.44	0.66	91.1
20N–8.8P–16.6K[u]	0.55	0.73	98.4	0.55	0.75	97.5	0.44	0.63	91.1
4N–0P–0.8K + organic amendment[t]	0.52	0.72	97.9	0.52	0.75	96.9	0.44	0.65	91.1
29N–0.9P–2.5K + organic amendment	0.51	0.77	97.5	0.53	0.78	95.0	0.40	0.63	91.2
20N–8.8P–16.6K + organic amendment	0.53	0.73	98.5	0.57	0.76	97.6	0.44	0.65	91.9
6N–0.9P–0K[s]	0.52	0.75	97.5	0.57	0.77	97.5	0.40	0.64	90.2
$LSD_{0.05}$[r]	0.03	0.02	0.1	0.03	0.02	0.1	NS	NS	NS
Foliar without organic amendment	0.53 a[q]	0.73 a	97.6 a	0.55 a	0.76 a	96.5 a	0.43 a	0.64 a	89.1 a
Foliar with organic amendment	0.52 a	0.74 a	98.0 b	0.54 a	0.76 a	96.5 a	0.43 a	0.64 a	91.4 b

[z] *mND* = modified normalized difference vegetation index (NDVI), $NDVI_{750/705}$ by including 445 nm in the reflection spectrum. $mND_{750/705} = (R_{750} - R_{705})/(R_{750} + R_{705} - 2R_{445})$, where *R* is the relative reflectance at a given wavelength.
[y] Dark green color index is a combination of hue, saturation, and brightness parameters of a digital image as a measurement of green color (Karcher and Richardson, 2003).
[x] Green density is the percentage of green pixels in the total pixels in each digital image (Richardson et al., 2001).
[w] Cytozorb-S (APT4M2X25; The Andersons, Maumee, OH) contains 4% nitrogen (N) from nitrate, 0.83% potassium (K) from potassium nitrate, 0.53% magnesium (Mg), 1% sulfur (S) from combined sulfur, 2% iron (Fe), 0.25% manganese (Mn), and 0.20% zinc (Zn).
[v] Nusion (APT2922X25, The Andersons) contains 29% total N (8.12% urea N, 20.88% other water-soluble slowly available N from urea-triazone solution), 0.88% phosphorus (P) from potassium polyphosphate, and 2.49% K from potassium polyphosphate.
[u] Jack's All Purpose (J.R. Peters, Allentown, PA) contains 20% total N (3.83% ammoniacal N, 6.07% nitrate N, 10.10% urea N), 8.8% available P from ammonia phosphate, 16.6% K from potassium nitrate, 0.05% Mg from magnesium sulfate, 0.0068% boron (B), 0.0009% molybdenum (Mo), 0.0036% chelated copper (Cu), 0.0500% chelated Fe, 0.0250% chelated Mn, and 0.0025% chelated Zn. All chelations are from ethylenediaminetetraacetic acid (EDTA).
[t] Rev™ (Dakota Peat, Grand Forks, ND) is derived from naturally mined humic materials with pH 6.2, 9.2 mg·kg⁻¹ nitrate N, 5.3 mg·kg⁻¹ ammoniacal N, 4 mg·kg⁻¹ P, and 10 mg·kg⁻¹ K. The material had particle sizes smaller than 100 µm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight; 1 mg·kg⁻¹ = 1 ppm, 1 µm = 1 micron.
[s] Milorganite (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) contains 6% total N (0.5% water-soluble N, 5.5% slow-release N), 0.88% P, and 4.0% Fe.
[r] Least significant difference at 0.05 *P* level.
[q] Numbers in the same column followed by same letter are not significantly different at 0.05 *P* level.

Table 3. Imagery quality of 'Penncross' creeping bentgrass as affected by foliar application of fertilizers and tank-mixed with liquid organic amendment in the second study of 2011. Liquid fertilizers (4N–0P–0.8K, 29N–0.9P–0.5K, 20N–8.8P–16.6K) were applied at 12.21 kg·ha^{-1} (10.894 lb/acre) nitrogen at 2-week intervals. Granular fertilizer (6N–0.9P–0K) was applied at 24.5 kg·ha^{-1} (21.86 lb/acre) nitrogen at 4-week intervals. Organic amendment was added in spray solution at 3% (v/v).

	1 Apr. 2011			14 May 2011			13 June 2011		
Treatment	*mND*[z]	DGCI[y]	Green density[x] (%)	*mND*	DGCI	Green density (%)	*mND*	DGCI	Green density (%)
4N–0P–0.8K[w]	0.58	0.71	99.4	0.58	0.65	99.6	0.67	0.62	99.8
29N–0.9P–2.5K[v]	0.28	0.60	81.9	0.57	0.68	99.6	0.58	0.50	99.6
20N–8.8P–16.6K[u]	0.43	0.60	95.7	0.59	0.65	98.5	0.55	0.49	100.0
4N–0P–0.8K + organic amendment[t]	0.59	0.68	99.1	0.59	0.66	99.6	0.69	0.61	99.9
29N–0.9P–2.5K + organic amendment	0.40	0.61	95.0	0.58	0.68	99.9	0.55	0.51	99.9
20N–8.8P–16.6K + organic amendment	0.43	0.58	93.6	0.59	0.69	99.6	0.57	0.49	99.6
6N–0.9P–0K[s]	0.40	0.58	91.9	0.57	0.68	99.6	0.56	0.49	99.9
LSD$_{0.05}$[r]	0.03	0.04	0.1	NS	0.02	0.2	0.02	0.02	NS
Foliar without organic amendment	0.43 a[q]	0.64 a	92.3 a	0.58 a	0.66 a	99.2 a	0.60 a	0.54 a	99.8 a
Foliar with organic amendment	0.47 b	0.62 a	95.9 b	0.59 a	0.68 b	99.7 b	0.60 a	0.54 a	99.8 a

[z]*mND* = modified normalized difference vegetation index (NDVI), NDVI$_{750/705}$ by including 445 nm in the reflection spectrum. $mND_{750/705} = (R_{750} - R_{705})/(R_{750} + R_{705} - 2R_{445})$, where R is the relative reflectance at a given wavelength.
[y]Dark green color index is a combination of hue, saturation, and brightness parameters of a digital image as a measurement of green color (Karcher and Richardson, 2003).
[x]Green density is the percentage of green pixels in the total pixels in each digital image (Richardson et al., 2001).
[w]Cytozorb-S (APT4M2X25; The Andersons, Maumee, OH) contains 4% nitrogen (N) from nitrate, 0.83% potassium (K) from potassium nitrate, 0.53% magnesium (Mg), 1% sulfur (S) from combined sulfur, 2% iron (Fe), 0.25% manganese (Mn), and 0.20% zinc (Zn).
[v]Nusion (APT2922X25, The Andersons) contains 29% total N (8.12% urea N, 20.88% other water-soluble slowly available N from urea-triazone solution), 0.88% phosphorus (P) from potassium polyphosphate, and 2.49% K from potassium polyphosphate.
[u]Jack's All Purpose (J.R. Peters, Allentown, PA) contains 20% total N (3.83% ammoniacal N, 6.07% nitrate N, 10.10% urea N), 8.8% available P from ammonia phosphate, 16.6% K from potassium nitrate, 0.05% Mg from magnesium sulfate, 0.0068% boron (B), 0.0009% molybdenum (Mo), 0.0036% chelated copper (Cu), 0.0500% chelated Fe, 0.0250% chelated Mn, and 0.0025% chelated Zn. All chelations are from ethylenediaminetetraacetic acid (EDTA).
[t]Rev™ (Dakota Peat, Grand Forks, ND) is derived from naturally mined humic materials with pH 6.2, 9.2 mg·kg^{-1} nitrate N, 5.3 mg·kg^{-1} ammoniacal N, 4 mg·kg^{-1} P, and 10 mg·kg^{-1} K. The material had particle sizes smaller than 100 μm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight; 1 mg·kg^{-1} = 1 ppm, 1 μm = 1 micron.
[s]Milorganite (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) contains 6% total N (0.5% water-soluble N, 5.5% slow-release N), 0.88% P, and 4.0% Fe.
[r]Least significant difference at 0.05 *P* level.
[q]Numbers in the same column followed by same letter are not significantly different at 0.05 *P* level.

except for the 20N–8.8P–16.6K fertilizer (Table 4). This was due to both root biomass increase and shoot biomass decrease in the amendment-added treatments (data not shown). No difference in root/shoot biomass ratio was observed from the addition of organic amendments in sand/peat root zones. This probably was because the major component, such as humic acid, already existed in sand/peat root zones. However, in both sand and sand/peat root zones, nitrate N fertilizer 4N–0P–0.8K had lower root/shoot biomass ratio than other fertilizer forms (Table 4). Pease et al. (2011) also reported that occasional poorer quality and less shoot density resulted from nitrate N than other N sources in velvet bentgrass (*Agrostis canina*). Since 20N–8.8P–16.6K liquid fertilizer also contains nitrate N, therefore, nitrate N may not be the only reason for the low root/shoot ratio. The 4N–0P–0.83K liquid fertilizer contains kelp, a sea weed extract that contains cytokinins and indole-3-acetic acid as reported by Zhang et al. (2003b). Future research is needed to separate the plant growth regulator effect of humic acids and the kelp component contained in liquid fertilizers.

Despite the increase of root/shoot ratio in 'Penncross' creeping bentgrass grown in sand root zones from adding organic amendment, the time to wilting after stopping irrigation was decreased by ≈0.4 d on average because of the addition of the organic amendment. The greater green density in tank-mixed treatments probably also had greater evapotranspiration (ET) than the treatments without the organic amendment (Tables 2 and 3), and therefore consumed water faster from the limited water supply in containers. Increased ET with increasing fertility levels also was reported in creeping bentgrass (Shearman and Beard, 1973) and kentucky bluegrass [*Poa pratensis* (Ebdon et al., 1999)]. However, further study is needed to test whether greater root/shoot biomass ratios can increase the time to wilting if more water is available in the root zone under field conditions. Bigelow et al. (2010) found that liquid fertilizer plus generic biostimulants helped a fast recovery of creeping bentgrass putting greens after core aeration. Further research is needed to test the drought tolerance of creeping bentgrass as affected by foliar fertilization with organic amendment under field conditions.

Conclusion

The results from this study showed that tank-mixing liquid organic amendment with liquid fertilizers commonly used in the turf industry could sustain equal or better visual quality without increasing the clipping yield of 'Penncross' creeping bentgrass maintained at 1-cm mowing height. Therefore, using this type of organic amendments may help reducing mowing requirements

Table 4. Root/shoot dry weight ratio and drought tolerance (days to wilting after stopping irrigation) of 'Penncross' creeping bentgrass as affected by foliar application of fertilizers and tank-mixed with liquid organic amendment with results combined from two studies in 2011. Liquid fertilizers (4N–0P–0.8K, 29N–0.9P–0.5K, 20N–8.8P–16.6K) were applied at 12.21 kg·ha^{-1} (10.894 lb/acre) nitrogen (N) at 2-week intervals. Granular fertilizer (6N–0.9P–0K) was applied at 24.5 kg·ha^{-1} (21.86 lb/acre) N at 4-week intervals. Organic amendment was added in spray solution at 3% (v/v). Data were combined from two studies because of the lack of interactions from study. The root/shoot ratios showed interaction between root-zone medium and fertilizer treatment, and therefore, are reported separately.

	Root/shoot ratio		
Treatment	Sand	Sand/peat	Time to wilting
4N–0P–0.8K[z]	0.39	0.29	7.4
29N–0.9P–2.5K[y]	0.72	0.46	9.6
20N–8.8P–16.6K[x]	0.74	0.57	11.0
4N–0P–0.8K + organic amendment[w]	0.44	0.28	7.1
29N–0.9P–2.5K + organic amendment	0.77	0.47	8.9
29N–0.9P–2.5K + organic amendment	0.74	0.57	10.6
6N–0.9P–0K[v]	0.80	0.58	11.1
$LSD_{0.05}$[u]	0.04	0.04	0.3
Foliar without organic amendment	0.62 a[t]	0.44 a	9.3 a
Foliar with organic amendment	0.65 b	0.44 a	8.9 b

[z]Cytozorb-S (APT4M2X25; The Andersons, Maumee, OH) contains 4% N from nitrate, 0.83% potassium (K) from potassium nitrate, 0.53% magnesium (Mg), 1% sulfur (S) from combined sulfur, 2% iron (Fe), 0.25% manganese (Mn), and 0.20% zinc (Zn).
[y]Nusion (APT2922X25, The Andersons) contains 29% total N (8.12% urea N, 20.88% other water-soluble slowly available N from urea-triazone solution), 0.88% phosphorus (P) from potassium polyphosphate, and 2.49% K from potassium polyphosphate.
[x]Jack's All Purpose (J.R. Peters, Allentown, PA) contains 20% total N (3.83% ammoniacal N, 6.07% nitrate N, 10.10% urea N), 8.8% available P from ammonia phosphate, 16.6% K from potassium nitrate, 0.05% Mg from magnesium sulfate, 0.0068% boron (B), 0.0009% molybdenum (Mo), 0.0036% chelated copper (Cu), 0.0500% chelated Fe, 0.0250% chelated Mn, and 0.0025% chelated Zn. All chelations are from ethylenediaminetetraacetic acid (EDTA).
[w]Rev™ (Dakota Peat, Grand Forks, ND) is derived from naturally mined humic materials with pH 6.2, 9.2 mg·kg^{-1} nitrate N, 5.3 mg·kg^{-1} ammoniacal N, 4 mg·kg^{-1} P, and 10 mg·kg^{-1} K. The material had particle sizes smaller than 100 µm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight; 1 mg·kg^{-1} = 1 ppm, 1 µm = 1 micron.
[v]Milorganite (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) contains 6% total N (0.5% water-soluble N, 5.5% slow-release N), 0.88% P, and 4.0% Fe.
[u]Least significant difference at 0.05 *P* level.
[t]Numbers in the same column followed by same letter are not significantly different at 0.05 *P* level.

and removal of clippings without sacrificing the turf quality. The effects on imagery quality were only ancillary to the visual quality evaluation but of limited practical impact. The benefit of applying the liquid organic amendment with liquid fertilizers in tank-mix also included increased root/shoot ratio grown in sand-based root zones. Many golf putting greens and tees are built of sand-based root zones, which have lower water-holding capacity compared with soil-based root zones. Field trials of tank-mixing organic amendments with liquid fertilizer are needed to test if the increased root/shoot ratio can contribute to drought tolerance in creeping bentgrass maintained at greens and fairway height in sand-based root zones.

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