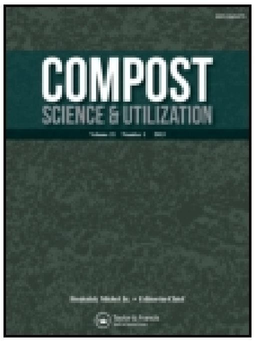

Compost Science & Utilization

ISSN: 1065-657X (Print) 2326-2397 (Online) Journal homepage: https://www.tandfonline.com/loi/ucsu20

Compost Practices for Improving Soil Properties and Turfgrass Establishment and Quality on a Disturbed Urban Soil

Gregory K. Evanylo, Shea N. Porta, Jinling Li, Dexin Shan, J. Michael Goatley & Rory Maguire

To cite this article: Gregory K. Evanylo, Shea N. Porta, Jinling Li, Dexin Shan, J. Michael Goatley & Rory Maguire (2016) Compost Practices for Improving Soil Properties and Turfgrass Establishment and Quality on a Disturbed Urban Soil, Compost Science & Utilization, 24:2, 136-145, DOI: 10.1080/1065657X.2015.1096866

To link to this article: https://doi.org/10.1080/1065657X.2015.1096866

Published online: 15 Dec 2015.

COMPOST SCIENCE & UTILIZATION
2016, VOL. 24, NO. 2, 136–145
http://dx.doi.org/10.1080/1065657X.2015.1096866

Taylor & Francis
Taylor & Francis Group

Compost Practices for Improving Soil Properties and Turfgrass Establishment and Quality on a Disturbed Urban Soil

Gregory K. Evanylo,[a] Shea N. Porta,[a] Jinling Li,[a] Dexin Shan,[b] J. Michael Goatley,[a] and Rory Maguire[a]

[a]Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA; [b]College of Resources and Environment, Northeast Agricultural University, Harbin, China

ABSTRACT

Urban land disturbance degrades physical, chemical, and biological soil properties by removing topsoil and compacting the remaining subsoil. Such practices create a soil environment that is unfavorable for vegetation establishment. A 3-year field study was conducted to compare the effects of various one-time compost application treatments on soil properties and re-vegetation of a disturbed soil. A disturbed urban soil received the following treatments: (1) inorganic fertilizer; (2) 2.5-cm-depth surface-applied compost; (3) 2.5-cm-depth incorporated compost; (4) 5.0-cm-depth incorporated compost; (5) inorganic fertilizer plus 0.6-cm compost blanket; and (6) inorganic fertilizer plus straw mat cover. The plots were seeded with a mixture of tall fescue *Festuca arundinacea* Shreb.: 'Magellan,' 'Coronado Gold,' 'Regiment,' and 'Tomcat,' perennial ryegrass *Lolium perenne* L. 'Linn', and Kentucky bluegrass *Poa pratenis* L. 'Baron.' Soil chemical and physical attributes and plant growth and quality parameters were measured during 840 days following study establishment. Soil C, N, P, K, Ca, and Mg, and turfgrass growth and quality were increased and soil bulk density was reduced by amending with composts. Incorporation of compost into soil improved soil and plant attributes more than unincorporated surface application, but the differences diminished with time. Compost benefits increased with time. One-time applications of compost can provide immediate and long-term benefits to soil and plant attributes, but there may be no need to incorporate the compost into soil, particularly if the soil has recently been loosened by tillage.

Introduction

Disturbed soils occur where natural soils are stripped of topsoil and are compacted by heavy machinery. The exposed subsoil typically is low in organic matter, biological activity, and plant available nutrients, and often possesses extremes in pH, high bulk density, and poor soil structure (Box 1978; Cogger 2005). These characteristics present challenges for turfgrass establishment and increase the likelihood of vegetation succumbing to environmental stress (Landschoot and McNitt 1994; Loschinkohl and Boehm 2001).

Compost utilized as a soil amendment can improve disturbed urban soils by increasing soil organic matter and essential plant nutrients (Cogger 2005; Singer et al. 2006). Organic matter improves soil physical properties, which are typically the most limiting attributes in disturbed soils. Such soil enhancement can improve turf establishment (Linde and Hepner 2005) and quality (Landschoot and McNitt 1994). The benefits of composts for improving soil properties and vegetation establishment vary according to compost properties and management. Landschoot (1995) and Powell (2012) recommend applications of 5.0-cm depth incorporated 10–15 cm for loam soils, whereas Farrell-Poe et al. (1997) recommend incorporating compost as deeply as possible into both fine and coarse textured soils. Application rates for compost are largely determined by economic considerations and vary from about 100 to 400 $Mg/ha/yr^{-1}$ on a dry weight basis (Cogger 2005).

Straw mulches or mats are recommended by the Virginia Department of Environmental Quality (DEQ 1992) as a best management practice for establishing vegetation on disturbed soils. Straw mats are designed to increase seed establishment by protecting seeds,

CONTACT Gregory K. Evanylo gevanylo@vt.edu Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, 426 Smyth Hall Blacksburg, VA 24061-0404.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ucsu.

maintaining moisture, permitting root development through the mat into the soil, and reducing weed seed germination (Hensler, Baldwin, and Goatley 2001). Drawbacks of straw mats are cost and removal damage to the established vegetation (Harrell and Miller 2005), and they do not ameliorate poor physical and chemical properties of disturbed soils. Compost may substitute for routine use of straw blankets that offer protection from erosion and desiccation. Reinsch et al. (2007) observed greater turf color and biomass in fescue sown under 5-cm compost blankets than straw mats.

Few studies have addressed the effects of compost on established turfgrass resilience to environmental stress. Zhang et al. (2009, 2012) demonstrated that the presence of biologically active substances (BAS), including humic substances, amino acids, and hormones, may enhance crop growth and quality by providing stress tolerance due to direct provision of BAS or production of BAS by microbial activity. Ervin, Zhang, and Schmidt (2005) reported that plant growth regulators enhanced turfgrass tolerance to such environmental stresses as temperature and UV radiation. BAS-containing compost may enhance turfgrass resilience and maintain photosynthetic activity after periods of environmental stress.

Our research group was asked to recommend practices that could be used to restore the productivity of and promote turfgrass establishment and growth in an urban soil whose topsoil was removed and subsoil compacted during adjacent construction. Landscapers had been unable to establish an acceptable stand of turfgrass on the site using only inorganic fertilizer and limestone for 4 years following the disturbance. The objective of this study was to evaluate various compost application practices for improving soil properties and resulting turfgrass establishment, quality, and resilience to environmental stress on a disturbed urban soil.

Materials and Methods

Field site description

The field site was located in Lynchburg, Virginia (Latitude 37° 21′ 16.40″ N, Longitude 79° 14′ 32.06″ W) on a soil stripped of topsoil and disturbed by residential construction. The soil was classified as a truncated Cecil (Fine, kaolinitic, thermic Typic Kanhapludult) subsoil (B-horizon). Lynchburg is located in the turfgrass transition zone, where warm and cool season grasses species are adapted. Mixtures of common species of turfgrass recommended for the establishment of residential lawns in Virginia include tall fescue (*Festuca arundinacea* Shreb.), Kentucky bluegrass (*Poa pratenis* L.), and perennial ryegrass (*Lolium perenne* L.).

Plot establishment and maintenance

Prior to plot establishment in March 2009, the field site was graded to a 2–3% slope with a power takeoff-driven, tractor-mounted roto-tiller to a depth of 10 cm and followed by surface smoothing with a harrow drag, which removed the sparse existing vegetation. Six treatments were replicated three times each in a randomized complete block design. The treatments included: (1) inorganic fertilizer control; (2) 2.5 cm compost (39.2 Mg ha^{-1}) surface-applied and unincorporated; (3) 2.5 cm compost (39.2 dry Mg ha^{-1}) surface-applied and incorporated to a depth of 7–10 cm; (4) 5.0 cm compost (78.4 Mg ha^{-1}) surface-applied and incorporated to a depth of 7–10 cm; (5) inorganic fertilizer plus 0.60 cm compost (9.8 Mg ha^{-1}) as seed blankets; and (6) inorganic fertilizer overlain with commercial straw blanket. All compost treatments were made on a one-time basis just prior to the turfgrass seeding. The treatments were established on fifteen plots measuring 18.2 m × 4.6 m (83.6 m^2) each.

The fertilizer control, 0.6 cm compost blanket, and the straw mat treatments received fertilizer according to the Virginia Tech Soil Testing Laboratory (VT-STL) recommendations (Maguire and Heckendorn 2015). Urea [$CO(NH_2)_2$; 460 mg N/g urea] was applied to plots by hand before planting to supply turfgrass establishment needs. All experimental plots also received supplemental basal inorganic P as diammonium phosphate (DAP; $NH_4H_2PO_4$; 180 mg N/g DAP, 460 mg P/g DAP) and K as muriate of potash (KCl; 600 mg K/g KCl) fertilizers based on soil testing results (Maguire and Heckendorn 2015).

The compost used was obtained locally (Royal Oak Farm, LLC, Lynchburg, VA, USA) and consisted largely of a 1:2 mixture of primary:secondary processed paper mill sludge and additional smaller fractions of complementary feedstocks, including woody waste, wood ash, food processing wastes from an infant formula manufacturing plant, and dissolved air flotation sludge from a potato food processing plant.

Compost was applied with a commercial topdressing spreader (Earth and Turf, New Holland, PA, USA). Fertilizer and compost were incorporated with a Ventrac EA600 Aera-vator (Venture Products Inc., Orrville, OH, USA).

All treatments were seeded with "Landscaper's Choice Mixture" (Evergreen Seed, LLC, Rice, VA, USA) at a rate of 448 kg ha^{-1}. The seed consisted of a 70% mixture of four varieties of tall fescue *Festuca arundinacea* Shreb.: 'Magellan', 'Coronado Gold', 'Regiment', and 'Tomcat'; 14% perennial ryegrass *Lolium perenne* L. 'Linn'; and 10% Kentucky bluegrass *Poa pratenis* L. 'Baron.' For the 0.6-cm compost blanket and the straw mat, seeding was performed immediately after fertilizer applications then covered with either the 0.60-cm compost blanket or a 100% straw fiber mat (North American Green® S150, Poseyville, IN, USA), which was pinned into the soil surface. The fertilizer control was seeded and aerovated in one pass. To the 2.5-cm surface compost application, seeds were broadcast on the compost surface without any tillage using a compost spreader. Seeding in the 2.5-cm- and 5.0-cm-depth compost incorporated treatments was performed after each of the plots were aerovated twice and subsequently rolled.

After establishment, all plots were mowed with a mulching mower monthly to a 5.0-cm height, and clippings were kept within their respective plots. A broadleaf herbicide, 'trimec' (2–4 D, MCPP, dicamba) was applied in July 2009 and May 2011 at a rate of 0.57 L ha^{-1}. All plots were also sprayed with 1.42 L mecamen d 0.23 kg prodiomine on May 13, 2011. In August 2009 and April 2011, a 23 kg ha^{-1} application of urea fertilizer was applied per recommendations for maintaining cool-season grasses in Virginia (Goatley, Askew, and Hardiman 2015). Despite the N supplied by the compost treatments and because no soil N tests exist for homeowners, all treatments received N fertilization in the fall of 2009 based upon turf visual assessments of color (Landschoot and McNitt 1994).

Soil and compost analyses

Soil samples comprising ten cores sampled to a depth of 10 cm were collected prior to treatment application in March 2009 ($t = 0$ days) and, thereafter, in September 2009 ($t = 180$ days) and July 2011 ($t = 840$ days) to assess treatment effects. The collected soil samples were air-dried for 72 h and ground to pass a 2-mm sieve before routine Virginia Tech soil test laboratory (STL) analysis for pH and Mehlich I-extractable P, K, Ca, and Mg (Maguire and Heckendorn 2015). The soil was analyzed for total organic C and total N via dry combustion on a VarioMax CNS analyzer (Elementar 2000).

Undisturbed soil cores (183.9 cm^3) were collected for bulk density determination by the drop hammer core method (Blake 1965) in triplicate from each treatment plot in May 2011. Vegetation was removed from the soil surface prior to sample collection. Soil dry weight was determined by weighing the subsamples after drying at 105°C until constant mass was obtained, and bulk density was calculated as the oven-dry mass of the sample divided by the sample volume.

Compost was analyzed by A&L Laboratories, Inc. (Memphis, TN, USA) for pH (USEPA 2004), electrical conductivity (EC; 1:2 compost to water), total solids (SM-2540G), total Kjeldahl N (SM-4500-TKN), ammonium-N (SM-4500-NH_3) (American Public Health Association 1992), phosphorus (SW-846-6010C), potassium (SW-846-6010C; USEPA 1986), and other macro and micro nutrients.

Compost total organic C and total N were measured via dry combustion on a VarioMax CNS analyzer (Elementar 2000). Compost maturity was determined using Solvita maturity index for CO_2 and NH_3 (Woods End, Mt. Vernon, ME, USA).

Biomass and turf quality

Biomass was harvested once a month during May 2009 ($t = 60$ days), July 2009 ($t = 120$ days), September 2009 ($t = 180$ days), October 2009 ($t = 210$ days), June 2010 ($t = 450$ days), May 2011 ($t = 780$ days), and July 2011 ($t = 840$ days) from a 0.5 m × 18 m (9 m^2) strip by mowing the center of each plot (0.5 m × 9 m or 4.5 m^2 for straw mat and compost blanket split plots) to a 5-cm height using a lawn mower equipped with a detachable bag. Sampling was performed at these times because they represented a mix of the most (May, June, September, October) and least (July) favorable environmental conditions for temperature zone, cool season turfgrass production. All biomass samples were dried in an oven at 65°C for 48 h or until constant mass was achieved for determination of dry weight.

Visual assessments of turf color and density were made on all treatment plots using a scale of 1 to 9

(1 = worst, 9 = best) according to the methods described by the National Turfgrass Evaluation Program (Morris 2004). The color assessments were made during July 2009 (t = 120 days), September 2009 (t = 180 days), October 2009 (t = 210 days), June 2010 (t = 450 days), and July 2011 (t = 840 days).

The density assessments were made during July 2009 (t = 120 days), September 2009 (t = 180 days), October 2009 (t = 210 days), June 2010 (t = 450 days), and September 2011 (t = 900 days).

Photochemical efficiency

In September 2009 and July 2011, chlorophyll fluorescence (Fv/Fm) was measured on all plots with a handheld dual wavelength fluorometer (OS-50 II, Opti-Sciences, Inc., Tyngsboro, MA, USA) as an indicator of photochemical response. The ratio of variable fluorescence to maximum fluorescence at 690 nm (Fv/Fm) is indicative of Photosystem II or relative photochemical efficiency (Zhang et al. 2009). Ten readings were measured from each plot. Senesced areas were avoided as measurements were too low for detection by the fluorometer. The Fv/Fm measurements from each plot were calculated based on the average of the ten readings.

Statistical analyses

The randomized complete block design was analyzed using a mixed model procedure of Statistical Analysis System (SAS) 9.2 (SAS Institute 2008). Analysis of variance (ANOVA) and least significant difference (LSD) measurement were applied at a level of 0.05 to compare differences of soil and turfgrass data between treatment means (SAS Institute 2008).

Results and Discussion

Compost properties

Analyses of the compost are presented in table 1. The compost solids content (565 g kg^{-1}) enabled it to be spread effectively. Its relatively high pH of 7.9 was due to the presence of papermill sludge ash in the product, which would have been expected to increase soil pH. The content of soluble salts, as indicated by an EC of 2.97 ds m^{-1} would not be expected to reduce seed germination or seedling vigor. The compost was determined to be "very mature" by Solvita CO_3 and NH_3 respiration tests. All other elements measured were within normal ranges.

Table 1. Composition of composts applied at study site in March 2009.

Parameter	Value
Maturity (Solvita)	Very mature
¼ in. screen size (%)	94
Solids (g kg^{-1})	565
EC (dS m^{-1})	2.97
pH	7.9
C:N	18:1
Total organic C (g kg^{-1})	300
Total N (g kg^{-1})	17.1
NH_4-N (g kg^{-1})	<0.2
NO_3-N (g kg^{-1})	9.7
Total Kjeldahl N (g kg^{-1})	7.4
P (g kg^{-1})	10
K (g kg^{-1})	14
Al (mg kg^{-1})	69.9
Ca (mg kg^{-1})	54.4
Fe (mg kg^{-1})	96.5
Mg (mg kg^{-1})	71.6
Na (mg kg^{-1})	<250

Note. Compost was analyzed by A&L Laboratories, Inc. (Memphis, TN) for pH (USEPA 2004), electrical conductivity (EC; 1:2 compost to water), total solids (SM-2540G), total Kjeldahl N (SM-4500-TKN), ammonium-N (SM-4500-NH_3; American Public Health Association 1992), phosphorus (SW-846-6010C), potassium (SW-846-6010C; USEPA 1986), total organic C and total N (dry combustion; Elementar 2000), and compost maturity (Solvita maturity index for CO_2 and NH_3, Woods End, Mt Vernon, ME, USA).

The application rates of C, N, P, and K supplied by the compost treatments are presented in table 2. The application of compost at the "routinely" recommended depths of 2.5 and 5.0 cm supplied P and K at rates determined to be adequate or higher than those recommended by the Virginia Tech Soil Testing Laboratory (Maguire and Heckendorn 2015) for the soil test values (table 3). The total N rate supplied by the compost, while appearing excessive, must be interpreted with the understanding that compost organic N typically mineralizes, or becomes plant-available, during the first year following application at a rate of approximately 10%. Therefore, the 2.5-cm-depth

Table 2. Carbon, nitrogen, phosphorus, and potassium rates applied with compost treatments and with the fertilizer as recommended by the Virginia Tech Soil Testing Laboratory recommendations (Maguire and Heckendorn 2015).

	C,	N	P	K
Thickness applied	Mg ha^{-1}	kg ha^{-1}		
Fertilizer	0	45	78	112
0.6 cm	3.2	131	98	157
2.5 cm	12.8	524	392	627
5.0 cm	25.6	1048	784	1254

Table 3. Soil properties measured by Virginia Tech Soil Testing Laboratory procedures (Maguire and Heckendorn 2015) in March 2009 prior to treatment application at study site.

pH	P	K	Ca	Mg	Zn	Mn
1:1 soil:water	Mehlich I, mg kg^{-1}					
7.1	7	178	2734	269	1.2	15

compost treatments supplied the approximate agronomic rate of plant available N (i.e., similar to the fertilizer N rate), and the 5.0-cm-depth application supplied approximately 2× the agronomic N rate. The added C from composts would be expected to increase soil aggregation and plant water availability, reduce soil bulk density, and improve soil physical properties that would be expected to improve the establishment and growth of the turfgrass.

Table 4. Soil properties measured by Virginia Tech Soil Testing Laboratory procedures (Maguire and Heckendorn 2015) and C and N by combustion (Elementar 2000) in September 2009 (180 days after treatment application) at study site.

	P	K	Ca	Mg	N	C	C:N
Treatment	Mehlich I, mg kg^{-1}				g kg^{-1}		
Fertilizer control	25 c	272 c	2056 c	173 c	0.68 bc	10 d	14.7 c
2.5 cm surface-applied compost	54 ab	531 b	4095 b	378 b	0.74 b	22 bc	29.7 a
2.5 cm incorporated compost	55 ab	558 b	5291 ab	412 b	1.39 b	27 b	19.4 b
5.0 cm incorporated compost	75 a	708 a	6410 a	500 a	1.78 a	37 a	20.8 b
0.6 cm compost blanket	30 c	350 c	2538 c	222 c	0.66 bc	12 cd	18.2 b
Straw mat cover	38 bc	314 c	2173 c	179 c	0.67 bc	10 d	14.9 c

Note. Means followed by the same letter in each column are not statistically different at $p < 0.05$.

Soil properties

The soil properties (as determined by Virginia Tech STL methods) of the truncated Cecil soil on the field site prior to treatment application are presented in table 3. For a disturbed urban (formerly Cecil series) soil in the Piedmont Physiographic Province, the soil test values are unusual. Such soils are typically very acid containing low amounts of P, Ca, and Mg. The neutral pH and high Ca and Mg concentrations were likely due to repeated attempts to rehabilitate the disturbed soils with high application rates of dolomitic limestone. Additional P and K were recommended by the STL (Maguire and Heckendorn 2015) for establishment of turfgrass. The STL recommended rates of N, P, and K were 45, 78, and 112 kg ha^{-1}, respectively.

The soil samples collected 180 days (table 4) and 840 days (table 5) after treatment application both exhibited significant treatment effects on soil properties. The concentrations of all soil nutrients were higher at 180 days than 840 days after establishment, and nutrients were highest in the compost-amended soils. The C and N concentrations showed the greatest differences among treatments throughout the study period, demonstrating the long-term residual effects of compost.

One of the main limitations for growing turfgrass in disturbed soils is the availability of soil nutrients. Previous studies show that plant available N, P, and K were absorbed by turfgrass roots within weeks (Chalmers and Whitt 2000). The remaining forms of elements in soils, mainly organic N, are slowly released in years or an even longer period (Cogger 2005). As expected, the 5.0-cm application depth of compost increased soil nutrients more than the 2.5-cm application depth. There was no difference between compost application method, i.e., surface application, and incorporation of a 2.5-cm rate on any soil nutrient at 180 days after establishment.

More than 2 years after plot establishment, i.e., 840 days later, soil elemental treatment differences were less apparent. The 5.0-cm incorporated compost maintained the highest level of elements among all

Table 5. Soil properties measured by Virginia Tech Soil Testing Laboratory procedures (Maguire and Heckendorn 2015) and C and N by combustion (Elementar 2000) in July 2011 (840 days after treatment application) at study site.

	P	K	Ca	Mg	N	C	C:N
Treatment	Mehlich I, mg kg^{-1}				g kg^{-1}		
Fertilizer control	21 a	145 ab	1626 ab	118 ab	0.99 bc	17 ab	17.2 a
2.5 cm surface-applied compost	17 ab	180 a	1970 ab	154 ab	1.25 ab	21 ab	16.8 a
2.5 cm incorporated compost	23 a	172 a	2191 a	161 ab	0.88 c	15 b	17.0 a
5.0 cm incorporated compost	22 a	202 a	2592 a	192 a	1.56 a	23 a	14.7 b
0.6 cm compost blanket	8 b	110 b	654 b	81 b	1.15 bc	21 ab	18.3 a
Straw mat cover	17 ab	164 ab	1332 ab	110 ab	0.98 bc	18 ab	18.4 a

Note. Means followed by the same letter in each column are not statistically different at $p < 0.05$.

treatments. The compost-treated soil maintained higher C, N, K, Ca, and Mg than the fertilizer controls, demonstrating improved soil properties by composts. The higher rate of compost maintained higher N and C concentration than the lower rate.

There was no difference between compost application method, i.e., surface application and incorporation of the 2.5-cm rate, on soil nutrients except for N at 840 days after amendment application, for which higher soil N occurred with the unincorporated treatment. Perhaps, the N in unincorporated compost was mineralized and lost more slowly from the soil system than the N in the soil-incorporated compost. The slow organic N pool is comprised of more resistant N compounds that take years for complete decomposition.

Neither the compost blanket nor the straw mat cover increased residual soil elemental concentrations above that achieved with the fertilizer control in the short or long term. Some of the lack of differences in soil elemental concentrations over time may have been due to treatment differences in nutrient assimilation and accumulation in the turfgrass crowns and tillers, as treatments did affect plant growth and density. As soil samples were collected to a depth of 10 cm, leaching of soil elements could also have contributed to differences.

Soil organic C concentrations were higher in compost-treated than fertilizer-treated soils. Previous studies (Li and Evanylo 2012; Spargo, Evanylo, and Alley 2006) showed that soil organic C concentration at 0–15-cm depth could be increased by compost addition over long time periods. Large application rates of composts organic C is significantly correlated with aggregate stability and erosion prevention (Shiralipour, McConnell, and Smith 1992), which can reduce further soil C loss (Bronick and Lal 2005).

Soil P concentrations were of great interest due to the high rates of P supplied by the 2.5- and 5.0-cm compost treatments (table 2). The 392 and 784 kg P/ha supplied 5× and 10×, respectively, the soil test recommended amounts of P. An increase in urban soil P due to excessive applications of fertilizers and/or organic amendments has been associated with surface water impairment due to runoff and erosion of particulate and soluble P (Easton and Petrovic 2004). Despite the high rates of P supplied by the compost treatments, soil test P never greatly exceeded 55 mg/kg, the Mehlich I extractable soil P level beyond which no additional fertilizer P is recommended (Maguire and Heckendorn 2015). This finding demonstrates the potentially high P binding capacity of fine-textured, Fe oxide-rich Piedmont subsoils that comprise many urban "topsoils." Typical compost rates of 2.5–5.0 cm (39–78 Mg/ha in this study) for rehabilitating urban disturbed soils may pose little water quality risk even when the mass of P applied is many times greater than recommended. Spargo, Evanylo, and Alley (2006) showed that the improved soil tilth and aggregation achieved with high application rates of compost could counteract the increased concentrations of total and water soluble P by increasing infiltration and reducing runoff and erosion. These results are important because they demonstrate that high compost loading rates can be safely applied to many urban soils formed from Fe-rich, fine-textured (i.e., clayey) subsoils despite the high P loading due to high soil P binding capacity and the improvement in physical properties (i.e., infiltration, bulk density, water-holding capacity) with compost addition that reduce loss of P via erosion and runoff.

Bulk density

Bulk density measured in May 2011 was affected by treatments ($p = 0.09$). The compost-treated soils had lower ($p < 0.05$) bulk densities than the fertilizer controls (mean = 1.33 g cm^{-3}). The 5.0-cm incorporated compost treatments (mean = 1.18 g cm^{-3}) had lower bulk density than the 2.5-cm incorporated compost treatments (mean = 1.25 g cm^{-3}). High bulk density is common in disturbed soils, and amending with compost is recommended to reduce bulk density. This study provides evidence that compost application can reduce bulk density even in soils not considered highly compacted. There was no significant bulk density difference between incorporated and unincorporated 2.5-cm applied compost treatments. Bulk density decreases in response to compost application is due to increases in porosity and aggregation (Cogger 2005; Khaleel, Reddy, and Overcash 1981). Pagliai, Vignozzi, and Pellegrini (2004) showed that soil treated with compost is less compactable than untreated soil.

Turfgrass growth

Time and treatment effects were significant for turfgrass biomass harvested between 2009 and 2011 (figure 1). After 60 days, biomass production was greatest with the rapidly soluble fertilizer N supplied by the control treatment ($p < 0.0001$). With time, the compost treatments produced the greatest biomass, as the inorganic fertilizer treatment was likely unable to continue to supply plant N needs and provide as favorable root zone environment for biomass production. Greater biomass was produced by the higher compost rate, likely due to the supply of greater plant available N. For the 2.5-cm-depth rate, soil incorporation increased biomass, likely as the compost in contact with the soil mineralized more rapidly. By the end of the initial year sampling ($t = 210$ days), the compost treatments consistently produced more biomass than the fertilizer treatments.

By June 2010 ($t = 450$ days), the incorporated compost treatments had greatly out-produced all other treatments. This trend was maintained throughout the remainder of the study. The 2.5-cm unincorporated compost treatment produced less biomass than the 2.5-cm incorporated and 5.0-cm compost treatments. Unincorporated compost may mineralize less slowly and also is at greater risk of runoff and erosion than is the incorporated compost. At 840 days after establishment, the inorganic fertilizer-only treatments had likely exhausted plant-available N and produced the lowest amount of biomass. The 5.0-cm incorporated compost treatment produced the most biomass, demonstrating the capability of improving turfgrass growing environment by composts. Biomass produced by all of the treatments was higher during 2010 than 2009 due to higher rainfall amounts.

Benik et al. (2003) reported greater biomass for straw mats than for bare soils or wood fiber mats, and Tormo, Bochet, and Garcia-Favos (2007) reported that wood fiber mats did not promote the dense vegetation. In our studies, the 0.6-cm compost blanket produced higher biomass harvests at $t = 450$, 780, and 840 days than did the straw mat. With increasing time, the difference between these two treatments widened.

Turfgrass quality

Turfgrass color difference among the treatments was significant (figure 2). The average turf color ratings increased over time, achieving the highest ratings in the first year of application (evaluated 210 days after establishment; figure 2). By June 2010 (450 days after establishment), the color ratings were similar among treatments. By July 2011 (840 days after establishment), the compost treatments had the highest color ratings. Similar to biomass, turf color ratings were lowest in fertilizer control and straw mat cover treatments. Across the five collection periods, there were no differences in turf color ratings among the treatments whose nutrition was largely supplied by inorganic fertilizer (i.e., fertilizer control, 0.6-cm compost

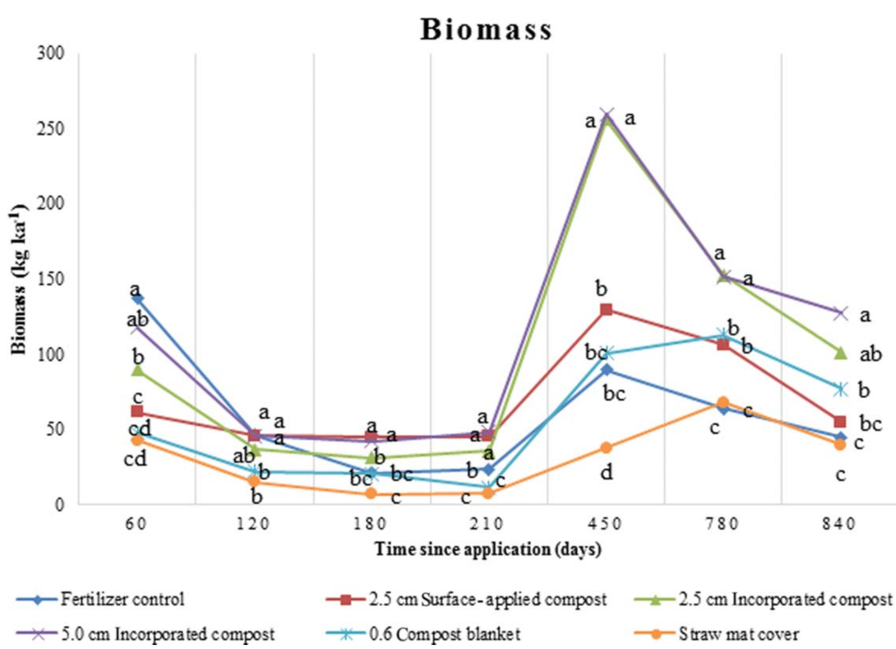

Figure 1. Turfgrass biomass establishment over application time (means between treatments under each recorded time period followed by the same letter in each column are not statistically different at $p < 0.05$).

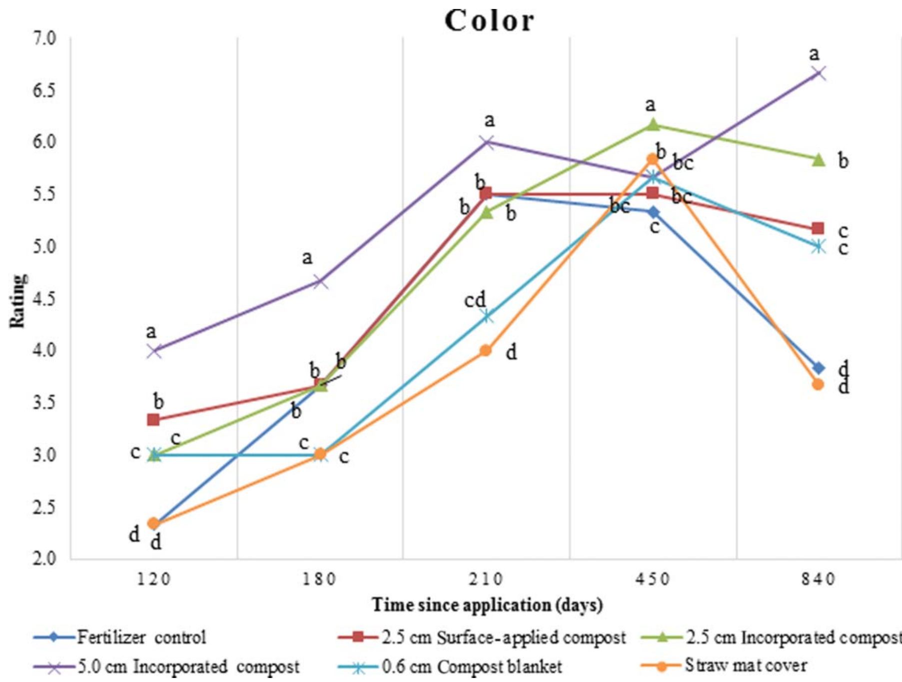

Figure 2. Turfgrass color ratings over application time (means between treatments under each recorded time period followed by the same letter in each column are not statistically different at $p < 0.05$).

blanket, and straw mat cover). Turfgrass receiving composts amendment achieved higher color ratings than the non-compost treatments, with the 5.0-cm compost treatment consistently giving the highest rating. For the 2.5-cm compost rate, color ratings were higher for the incorporated than for the unincorporated treatment.

All color ratings were below 6, the critical value for acceptable turf (Morris 2004), except the 5.0-cm compost treatment which peaked at 6.7 in July 2011. Prior

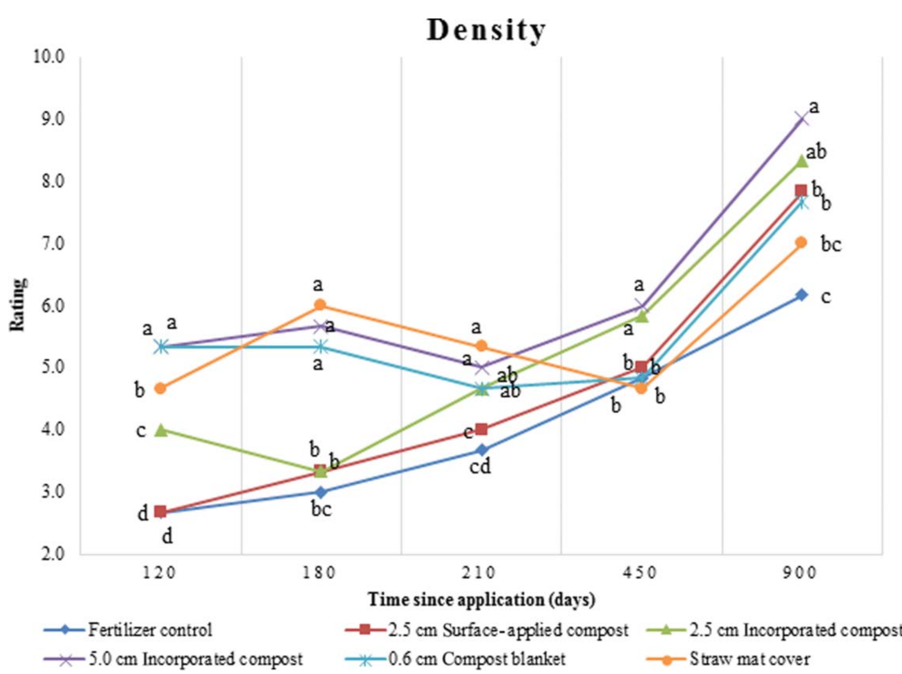

Figure 3. Turfgrass density ratings over application time (means between treatments under each recorded time period followed by the same letter in each column are not statistically different at $p < 0.05$).

to N fertilization in September, there were no differences in color assessments between July ($t = 120$ days) and September 2009 ($t = 180$ days); however, color ratings increased in all treatments in October 2009 ($t = 210$ days) following September N fertilization.

All mean turfgrass density ratings were below the minimum value of 6 described as acceptable turf (NTEP 2009), except the ratings recorded at the last time period in September 2011. This was likely due to the stressful environmental conditions encountered by the turfgrass throughout much of the study period. Turfgrass density varied among the treatments, increasing over time and peaking in September 2011 ($t = 900$ days) (figure 3). The fertilizer control had the lowest density throughout the entire 3 years of observation, while the 5.0-cm compost treatment gave the highest density at nearly every rating period. Turfgrass density was higher where the 2.5-cm compost rate was incorporated than unincorporated in July 2009 ($t =$ 120 days); however, this difference diminished with time, perhaps due to surface compost incorporation by soil organisms. The early greater density in the 5.0 than in the 2.5-cm compost treatments decreased with time. The straw mat cover had high density ratings in the first year of application but decreased sharply in the subsequent years. These results were consistent with those of Linde and Hepner (2005), who showed that improved turfgrass density in soils amended with biosolids compost (compared to those inorganically fertilized) was due, in large part, to the improved chemical properties (including nutrition) in the compost-amended soils.

Turfgrass color and density are important criteria for assessing vegetation quality. This study showed that compost-treated plots maintained higher color and density ratings and, thus, better turf quality than the non-compost treatments. Also, incorporation of compost could maintain better quality than unincorporated surface-applied compost. The infrequent N application employing this low input system was insufficient to maintain a high quality turfgrass, yet the one time applications of compost prior to planting maintained a surprisingly good stand throughout the study period.

Photochemical efficiency

Differences in photochemical efficiency (PE) measurements collected from the canopies of the six treatments were not statistically significant for treatment effects ($P = 0.32$). The average photochemical efficiency (Fv/Fm) for all treatments was 0.62 in 2009 and 0.82 in 2011. Optimum Fv/Fm values are 0.83 for most plants, whereas values below 0.83 are evidence of stress (Bjorkman and Demmig 1987). Moisture stress can reduce photochemical efficiency values in tall fescue (Zhang et al. 2009). The use of organic amendments has been shown to improve the resilience of turfgrasses grown under environmental stress (Zhang et al. 2012); however, we did not measure any physiological benefits (i.e., PE) in response to compost treatments.

Conclusions

Disturbed urban soils, whose properties include high bulk density, low porosity, poor tilth and aggregation, and low contents of carbon, nitrogen, phosphorus, and other organic matter-associated nutrients, provide poor conditions for vegetation establishment and growth. Although readily soluble inorganic fertilizer may produce a rapid beneficial response, compost provides longer lasting residual benefits that can maintain a soil pool of C, N, and other essential plant nutrients. High soil bulk density can be reduced and turfgrass growth and quality can be improved with compost, and the benefits increase with higher application rate. Compost incorporation results in a more rapid improvement in soil and plant response, but the long-term effects are more directly associated with application rate.

Acknowledgement

The authors wish to thank Dr. Xunzhong Zhang for his technical expertise with the photochemical efficiency methodology.

Funding

Funding for this work was provided in part by the Virginia Agricultural Experiment Station and the Hatch Program of the National Institute of Food and Agriculture, U.S. Department of Agriculture, The National Fish and Wildlife Foundation, and the Mid Atlantic Compost Association.

References

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hansen, and D. Stenlund. 2003. Performance of erosion control products on a highway embankment. *Transactions of the ASAE* 46:1113–19.

Blake, G. R. 1965. Bulk density. In *Methods of soil analysis part 1*, ed. C. A. Black. Madison, WI: American Society of Agronomy.

Bjorkman, O., and B. Demmig. 1987. Photon yield of O_2 evolution and chlorophyll fluorescence characteristics at 77 k among vascular plants of diverse origin. *Planta* 170:489–504.

Box, T. W. 1978. The significance and responsibility of rehabilitating drastically disturbed lands. In *Reclamation of drastically disturbed lands*, ed. F. W. Schaller and P. Sutton, 1–10. Madison, WI: American Society of Agronomy.

Bronick, C. J., and R. Lal. 2005. Soil structure and management: A review. *Geoderma* 124:3–22.

Chalmers, D. R., and D. L. Whitt. 2000. Turfgrass. Part III. In *Agronomy handbook*, 41–52. Blacksburg, VA: Virginia Tech Cooperative Extension.

Cogger, C. G. 2005. Potential compost benefits for restoration of soils disturbed by urban development. *Compost Science and Utilization* 13:243–51.

Easton, Z. M., and A. M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. *Journal of Environmental Quality* 33:645–55.

Elementar. 2000. *Instruction manual*. Laurel, NJ: Elementar America, Mt.

Ervin, E. H., X. Zhang, and R. E. Schmidt. 2005. Exogenous salicylic acid enhances post-transplant success of heated Kentucky bluegrass and tall fescue sod. *Crop Science* 45:240–44.

Farrell-Poe, K., R. Koenig, B. Miller, and J. Barnhill. 1997. Using compost in Utah turf applications. *HG/Compost/03*. Logan, UT: Utah State University Extension.

Goatley, M., W. Askew, and T. Hardiman. 2015. 2015–2016 Virginia Turfgrass Variety Recommendations. Virginia Cooperative Extension Publication CSES-17NP. http://pubs.ext.vt.edu/CSES/CSES-17/CSES-17.html (accessed February 3, 2015).

Harrell, M. S., and G. L. Miller. 2005. Composted yard waste affects soil displacement and roadside vegetation. *HortScience* 40:2157–63.

Hensler, K. L., B. S. Baldwin, and J. M. Goatley, Jr. 2001. Comparing seeded organic-fiber mat with direct soil seeding for warm-season turfgrass establishment. *HortTechnology* 11:1063–98.

Khaleel, R., K. R. Reddy, and M. R. Overcash. 1981. Changes in soil physical properties due to organic waste applications: A review. *Journal of Environmental Quality* 10:133–41.

Landschoot, P. R. 1995. Using composts to improve turf performance. *Penn State University Cooperative Extension*. http://turfgrassmanagement.psu.edu/composts.cfm (accessed March 17, 2010).

Landschoot, P. R., and A. McNitt. 1994. Improving turf with compost. *Biocycle* 35:54–57.

Li, J., and G. K. Evanylo. 2012. The effects of long-term application of organic amendments on soil organic carbon accumulation. *Soil Science Society of America Journal* 77:964–73.

Linde, D. T., and L. D. Hepner. 2005. Turfgrass seed and sod establishment on soil amended with biosolid compost. *HortTechnology* 15:577–83.

Loschinkohl, C., and M. J. Boehm. 2001. Composted biosolids incorporation improves turfgrass establishment on disturbed urban soil and improves leaf rust severity. *HortScience* 36:790–94.

Maguire, R. O., and S. E. Heckendorn. 2015. Soil test recommendations for Virginia. Blacksburg, VA: Virginia Cooperative Extension. http://www.soiltest.vt.edu./PDF/recommendation-guidebook.pdf (accessed January 13, 2015).

Morris, K. A guide to NTEP turfgrass ratings. National Turfgrass Evaluation Program. http://www.ntep.org/reports/ratings.htm#quality (accessed May 12, 2013).

Pagliai, M., N. Vignozzi, and S. Pellegrini. 2004. Soil structure and the effect of management practices. *Soil and Tillage Research* 79:131–143.

Powell, A. J. 2000. *Lawn establishment in Kentucky*. AGR-50. University of Kentucky Cooperative Extension Service. http://www.ca.uky.edu/agc/pubs/agr/agr50/agr50.pdf.

Reinsch, C. T., D. M. Admiraal, B. I. Dvorak, C. A. Cecrle, T. G. Franti, and J. S. Stansbury. 2007. Yard waste compost as a stormwater protection treatment for construction sites. *Water Environment Research* 79:868–76.

SAS Institute Inc. 2008. SAS 9.3. Cary, NC: SAS Institute Inc.

Singer, J. W., R. W. Malone, M. D. Tomer, T. G. Meade, and J. Welch. 2006. Compost effect on water retention and native plant establishment on a construction embankment. *Journal of Soil and Water Conservation* 61:268–73.

Shiralipour, A., D. B. McConnell, and W. H. Smith. 1992. Physical and chemical properties of soils as affected by municipal solid waste compost application. *Biomass and Bioenergy* 3:261–66.

Spargo, J. T., G. K. Evanylo, and M. M. Alley. 2006. Repeated compost application effects on phosphorus runoff in the Virginia Piedmont. *Journal of Environmental Quality* 35:2342–51.

American Public Health Association. 1992. SM-4500. In *Standard methods for the examination of water and wastewater*. Washington, DC: American Public Health Association.

U.S. Environmental Protection Agency (USEPA). 1986. EPA/SW-846. In *Test methods for evaluating solid waste*. Washington, DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (USEPA). 2004. Soil and waste pH. Method 9045D. http://www3.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/9045d.pdf (accessed February 7, 2012).

Tormo, J., E. Bochet, and P. Garcia-Favos. 2007. Roadfill revegetation in semi-arid Mediterranean environments. Part II: Topsoiling, species selection and hydroseeding. *Restoration Ecology* 15:97–102.

Virginia Department of Environmental Quality (DEQ). 1992. Topsoiling. Chapter 3.30. Virginia erosion and sediment control handbook, 3rd ed. http://www.deq.virginia.gov/Portals/0/DEQ/Water/StormwaterManagement/Erosion_Sediment_Control_Handbook/Chapter 3 - 3.30.pdf (accessed 21 August 2013).

Zhang, X., E. H. Ervin, G. K. Evanylo, and K. C. Haering. 2009. Impact of biosolids on hormone metabolism in drought-stressed tall fescue. *Crop Science* 49:1893–901.

Zhang, X., D. Zhou, E. H. Ervin, G. K. Evanylo, D. Cataldi, and J. Li. 2012. Biosolids impact antioxidant metabolism associated with drought tolerance in tall fescue. *HortScience* 47:1550–55.