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Managing and Protecting Quality Turfgrass Areas: Assessing the Impact of Leaf Compost Topdressing on Organically Managed Athletic Fields and Evaluating the Effects of Portable Roadway Systems on Turfgrass Performance and Soil Physical Properties

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Chapter 1

Protecting the quality and integrity of turfgrass surfaces during non-sporting events with portable roadways

Abstract

Many current sports venues routinely host non-sporting events that require vehicular traffic over playing surfaces. These events often occur during the season of play and are a challenge to sports turf managers to protect the playing surface. The objectives of this study were to determine the effects of portable roadways on: 1) percent cover, color, and quality, 2) surface hardness and rotational traction, and 3) volumetric soil moisture, bulk density, total porosity, and soil displacement. Five protection systems were evaluated for multiple cover periods (3, 6, and 9 days): 1) ¾" Plywood (2 pcs), 2) Enkamat Plus and Plywood (2pcs), 3) Enkamat Flatback and Plywood (2pcs), 4) Supa-Trac™ and 5) TerraTrak Plus™. An untraffiked control was included. This study was conducted on a mixed stand of Kentucky bluegrass and perennial ryegrass during year 1, and on a monostand of Kentucky bluegrass during year 2. Vehicular traffic was imposed using a truck (gross vehicle weight rating of 20,000 lbs.). Minimal differences in percent cover were observed after the three day cover period. As the cover duration increased, TerraTrak Plus and Supa-Trac retained better color and cover than all the plywood treatments. TerraTrak Plus retained the best color after six and nine days. The plywood treatments provided the best protection against displacement and compaction given the load range tested.

Introduction

Many current sports venues routinely host non-sporting events on their natural turf fields. Many of these events require vehicular traffic over the playing surfaces to set up stages, seating, and other event specific equipment. Retaining a playable surface throughout the event process poses a tremendous challenge to sports turf managers since many of these events occur during the season of play. Given the limited amount of time for re-establishing from seed, and the cost of resodding, there has been serious inquiry as to the most effective turfgrass cover protection system for maintaining the integrity of the playing surface during non-sporting events.

Covers have been researched to enhance spring green up, enhance turfgrass quality, and extend the growing season in various regions (Goatley et al., 2005 and Minner et al., 2001). The use of impermeable covers over insulating material has been used to reduce winterkill on golf greens (Dionne et al., 1999). In the southern United States, covering bermudagrass (*Cynodon dactylon)* with polypropylene turf blankets when night temperatures were predicted to be less than 4°C extended acceptable turf quality by 5 to 8 weeks (Goatley et al., 2005). Research has also shown that tarp color can significantly affect turf color, growth, and ultimately the amount of turf cover after injured turf recovers (Minner et al., 2001). However, research on covers utilized as portable roadways is lacking. The objectives of this study were to determine the effects of portable roadway systems on: (i) percent green cover, turfgrass color, and turfgrass quality, (ii) surface hardness and rotational traction, and (iii) volumetric soil moisture, bulk density, total porosity, and soil displacement.

Materials and Methods

This study was conducted at the University of Connecticut Plant Science Research and Education Facility located in Storrs, CT, during the 2010-2011 and 2011-2012 growing seasons. The soil in the research area was a Woodbridge loam sandy loam (Coarse-loamy, mixed, active, mesic Aquic Dystudepts) with a pH of 6.1, 52% sand, 34% silt, 14% clay, and 6% organic matter by weight. During the 2010-2011growing season, the study was performed on a mixed stand of 85% ‘Granite’ Kentucky bluegrass (*Poa pratensis* L.) and 15% ‘Fiesta 4’ perennial ryegrass (*Lolium perenne* L.). During the 2011-2012 growing season, the study was performed on a monostand of Kentucky bluegrass (33% ‘P-105’, 33% ‘Brilliant’, and 33% ‘Midnight II’). In both seasons, the study was initiated in June and repeated in August. Treatments were arranged as a 3 × 6 (cover duration × cover type) factorial in a split plot design with three replications. The main plots (cover duration) were split by cover type. The five turf protection systems evaluated were: 1) ¾” Plywood only (2 layers), 2) Enkamat Plus and ¾” Plywood (2 layers) (Fig. 1.1), 3) Enkamat Flatback and ¾” Plywood (2 layers) (Fig. 1.2), 4) Supa-Trac^{TM} (Rola-Trak North America) (Fig. 1.3), 5) TerraTrak Plus^{TM} (Terraplas, Inc.) (Fig. 1.4), and 6) an uncovered control. The second factor, cover duration, had three levels: 3, 6, and 9 days. Treatments were subjected to two traffic events; each consisted of 10 passes perpendicular to treatments with a loaded dump truck (Fig. 1.5) (GVWR = 20,000 lbs) (Table 1.1). Traffic events were conducted on the first and last day of each cover period.

During the first year of the study, the first cover period was from 23 June 2010 to 2 July 2010. The second cover period lasted from 10 August 2010 to 19 August 2010. Plot sizes were 4 feet wide by 12 feet long, mowed three times per week at 2 inches with a zero-turn rotary mower (Scag Power Equipment, Mayville, WI), and the clippings were returned. Plots were re-

randomized and the study was repeated during the 2011-2012 growing season in a new research area established to Kentucky bluegrass. Traffic events were conducted on the first and last day of each cover period. The first cover period lasted from 21 June 2011 to 30 June 2011. The second cover period lasted from 23 August 2011 to 1 September 2011. Plot sizes were 4 feet wide by 12 feet long, mowed three times per week at 1.5 inches with a Toro Grounds Master 3505-D (The Toro Company, Bloomington, MN), and the clippings were returned.

Fertility

A pre-study soil nutrient analysis indicated that nitrogen, phosphorus, and potassium levels were above the critical limits, and thus a maintenance type of fertility program was utilized. During the first year of the study, fertilizer treatments (46-0-0) were applied on 21 to 24 day intervals to the entire study area starting 7 May 2010 through 27 September 2010 for a total application of 5.2lbs N 1000 ft^{-2} (256 kg N ha^{-1}). Phosphorous (18-9-18) was applied on 13 July 2010 and 6 October for a total application of 0.62 lbs P_2O_5 1000 ft^{-2} (31 kg P_2O_5 ha^{-1}). Potassium (18-9-18) was applied on 13 July 2010 and 6 October 2010 for a total application of 1.25 lbs K_2O 1000 ft^{-2} (61 kg K_2O ha^{-1}). Plots were irrigated as needed to prevent moisture stress.

During the second year of the study, fertilizer treatments (46-0-0) were applied on 18 to 21 day intervals to the entire study area starting 3 June 2011 through 13 October 2011 for a total application of 5.4 lbs N 1000 ft^{-2} (268 kg N ha^{-1}). Phosphorous (18-9-18) was applied on 7 July 2011, 2 September 2011, and 13 October 2011 for a total application of 1 lb P_2O_5 1000 ft^{-2} (50 kg P_2O_5 ha^{-1}). Potassium (18-9-18) was applied on 7 July 2011, 2 September 2011, and 13 October 2011 for a total application of 2 lbs K_2O 1000 ft^{-2} (98 kg K_2O ha^{-1}). Plots were irrigated as needed to prevent moisture stress.

Data Collection

Data collected in this study included turfgrass performance (percent green cover, color, turfgrass quality), playing surface characteristics (surface hardness and traction) soil physical properties (volumetric moisture content, bulk density, total porosity), and soil displacement. Data were collected immediately following cover removal after each cover period. Undisturbed soil samples were extracted from within the tire tracks of each plot at the end of each year (2 subsamples from each plot) to measure soil physical properties (bulk density and total porosity). Turfgrass color was determined using digital image analysis. Digital images were taken prior to covers being applied and then taken immediately following each cover period. Controlled light conditions were provided through the use of a light box (Karcher and Richardson, 2005). Photos were taken between the tire tracks on each plot. Images were scanned using Sigma Scan Software v. 12.5 (Cranes Software International Limited, Chicago, IL) using the following threshold values; hue=55-125 and saturation=10-100. The Dark Green Color Index (DGCI) was calculated based on hue, saturation, and brightness values (Karcher and Richardson, 2003). Plots were rated after each cover period for percent green cover, turfgrass color, and turfgrass quality. Turfgrass quality was rated visually on a scale of 1 to 9, where 1=brown/dead turf; 6=minimum acceptable color/quality; and 9=optimum quality. Surface hardness was measured using a 5 lb (2.25 kg) Clegg Hammer (Clegg, Western Australia) that was utilized inside the tire tracks of each plot (Clegg, 1976). Clegg measurements were an average of six single drops of the missile within each plot (ASTM, 2008). Traction was measured using a Canaway Traction Device (Canaway and Bell, 1986). Displacement was measured using a custom designed apparatus with five measuring pins spaced 10.2 cm across the tire track to measure the depth of the rut produced by the dump truck. These reading were averaged across both tire tracks. Volumetric soil moisture

measurements were an average of six readings, randomly taken per plot, using a Field Scout TDR 300 Soil Moisture Meter (Spectrum Technologies, Inc., Aurora, IL) equipped with two 1.5 inch measuring rods. Following the second cover period, two 1.85 inch diameter undisturbed soil cores, representing a depth of 0 to 3 inches, were randomly taken from each treatment in the area where the tires traveled using an AMS soil core sampling device (Model 404.67, AMS, Inc., American Falls, ID). Saturated hydraulic conductivity was determined using a constant-head flow (ASTM F1815-06, 2006). Bulk density was measured using the oven dry mass of the soil and the volume of the cores (ASTM F1815-06, 2006). Samples from each core were sent to an independent lab for particle density analysis (ASTM D5550-06, 2006) (Hummel and Co., Inc., Trumansburg, NY). Aeration porosity was determined by subtracting the capillary porosity, measured gravimetrically after 72 hours using a porous plate and pressure chamber at -33.3 kPa (ASTM D6836-02, 2002), from the total porosity, calculated from the bulk and particle densities (ASTM F1815-06, 2006).

Statistical Analysis

Cover periods and years were combined using analysis of variance with the mixed procedure of SAS statistical software v. 9.3 (SAS Institute, Cary, NC). Cover period (June and August) were considered fixed and years were considered random. Where ($p \leq 0.05$) differences between treatments using appropriate F-tests showed significance, mean separations were conducted using Fisher's LSD test with a 0.05 probability level.

Results

Percent Green Cover

Following the 3 day cover period, Supa-trac and Terra Trak Plus had the highest percent green cover values of the covered treatments (Fig. 1.6). The three plywood treatments (Enkamat Flat, Enkamat Plus, and Plywood Only) had significantly lower percent green cover when compared to Supa-trac and Terra Trak Plus, however they were not significantly different from the Control or No Cover with Traffic treatments. Following the 6 day cover period, the Control, No Cover with Traffic treatment, Supa-trac, and Terra Trak Plus had the highest percent green cover. Enkamat Flat had slightly less cover than Plywood Only. Following the 9 day cover period, the Control, No Cover with Traffic treatment, and Terra Trak Plus retained significantly higher percent green cover when compared to all other treatments, but were not statistically different from each other. Supa-trac had significantly higher percent green cover when compared to the three plywood treatments. The Plywood Only treatment retained significantly higher percent green cover when compared to Enkamat Flat and Enkamat Plus.

Color

The Control and No Cover with Traffic treatment retained the darkest color after the 3 day cover period (Fig. 1.7). Terra Trak Plus had the highest color retention among plots that were covered, however it was not statistically different from Supa-Trac. Enkamat Plus, Enkamat Flat, and Plywood Only were not significantly different, and had the lowest color retention when compared to all other treatments. Following the 6 and 9 day cover periods, the No Cover with Traffic treatment had the highest retention in color, but was not significantly different from the Control. Terra Trak Plus had the highest color retention among covered plots and it was not

statistically different from the Control after the 6 day cover period. All plywood treatments retained considerably less color than Terra Trak Plus or Supa-trac following both the 6 and 9 day cover periods.

Quality

The Control had the highest turfgrass quality across all three cover periods, while Terra Trak Plus had the second highest turfgrass quality rating across all three cover periods (Fig. 1.8). Following the 3 day cover period, the three plywood treatments had significantly higher turfgrass quality ratings when compared to Supa-trac and the No Cover with Traffic treatment. The reduction in quality of the Supa-Trac treatment compared to the plywood treatments and No Cover with Traffic was primarily due to the bottom of the Supa-trac cutting into the turfgrass stand creating a “cookie cutter appearance”, and the significant rutting with the uncovered treatment. Following the 6 and 9 day cover periods, the No Cover with Traffic treatment and Supa-trac were not significantly different from each other, but had significantly higher turfgrass quality ratings than the three plywood treatments. The three plywood treatments were not significantly different from each other during the 6 and 9 day cover periods.

Volumetric Moisture Content

Based on the data, the plots that were covered retained more water during the cover periods (Fig. 1.9). This demonstrates the importance of drying fields down prior to the cover period to reduce the amount of moisture that can accumulate at the soil surface/cover interface.

Surface Hardness

The Control had significantly lower surface hardness readings compared to all other plots (Fig. 1.10) following the 3 day cover period. No significant differences were detected between cover treatments. Following the 6 day cover period, Enkamat Flat and Enkamat Plus were the only cover treatments that had significantly higher surface hardness compared to the No Cover/No Traffic control. Supa-trac had the lowest surface hardness values, but was not significantly different from the Control or the No Cover with Traffic treatment. Following the 9 day cover period, the No Cover with Traffic treatment had the highest surface hardness value, while Supa-trac and the Control had the lowest. Terra-Trak Plus, Enkamat Flat, Enkamat Plus, and Plywood only showed no significant differences following the removal of the 9 day covers.

Rotational Traction

Few differences in rotational traction were observed for the 3 and 6 day cover periods (Fig. 1.11). Following the 9 day cover period, the Control had significantly higher traction values when compared to all other treatments. The No Cover with Traffic treatment, Supa-trac, Terra Trak Plus, Enkamat Plus, and Plywood Only were not significantly different from each other following the removal of the 9 day covers. Enkamat Plus had significantly lower traction values when compared to the Control, No Cover with Traffic treatment, Terra Trak Plus, and Enkamat Plus. Even though there were differences in the rotational traction data, all values obtained on each treatment were above the accepted minimum of 10 N·m (Bell and Holmes, 1988).

Bulk Density

Supa-trac and the No Cover with Traffic treatment had significantly higher bulk densities when compared to all treatments except Terra Trak Plus (Fig. 1.12). Terra Trak Plus had significantly higher bulk densities than Plywood Only and Enkamat Plus, but was not significantly different from Enkamat Flat. Plywood Only and Enkamat Plus had significantly lower bulk density values among the plots that received covers, but were not significantly different from Enkamat Flat.

Total Porosity

The Control had significantly higher total porosity values when compared to all other treatments (Fig. 1.13). Enkamat Plus and Plywood Only had significantly higher total porosity values when compared to Supa-trac. No differences between the plywood treatments were observed. Supa-trac had significantly lower total porosity values when compared to all other treatments except No Cover with Traffic.

Displacement

The No Cover with Traffic treatment had significantly higher displacement values when compared to all other treatments (Fig. 1.14). Supa-trac had the most displacement among covered plots. The three plywood treatments were not significantly different from each other, but showed a significant reduction in displacement among all covered plots. The control had the least amount of displacement when compared to all plots.

Discussion

The primary challenges associated with covering the turf system of an athletic field are minimizing any disruption to the surface while maintaining acceptable turf color, cover, and quality. The type of cover used will depend on the loads being applied to the playing surface and duration of the event being held.

Given the load range tested, the plywood treatments provided the best protection against displacement, had the highest total porosity rates, and had the lowest bulk density values. There was little soil disturbance due to the plywood's ability to displace the weight of the vehicle. There were no observed benefits when Enkamat Plus or Enkamat Flat was placed under the plywood for added protection. If covering turfgrass areas with plywood for more than 3 days, a considerable drop in percent green cover, turf color, and turfgrass quality should be expected. In addition to the limited cover period associated with plywood use, it can also be difficult to handle due to the size/weight of the individual 4 ft × 8 ft sheets and inevitably numerous wood splinters are likely to be left behind on the playing surface after the plywood has been removed.

Terra Trak Plus retained significantly better percent green cover and color, and had significantly higher turfgrass quality compared to all other cover treatments across all cover periods. Since Terra Trak Plus is made from a semi-translucent plastic, some photosynthetic light was able to pass through the cover enabling the turfgrass to maintain its green color. Terra Trak Plus had lower bulk density and total porosity values, and displaced the load better than Supa-trac, but not as well as any of the plywood treatments. Due to the thinness and/or the flex of Terra Trak Plus, the soil surface had some minor rutting at the load range tested.

Supa-trac also did not perform as well as plywood and Terra Trak Plus regarding maintaining the integrity of the playing surface when subjected to a vehicular load. Supa-Trac is

made out of a light, non-translucent plastic that has hinges along the surface allowing it to form to the undulations of the ground. This design did not allow Supa-trac to displace the weight of the vehicle like the plywood treatments or Terra Trak Plus. This resulted in increased soil displacement, lower quality ratings and decreased total porosity values. Additionally, the underside of Supa-trac was not flat. Instead, it had a raised rectangular grid pattern that resembled a honeycomb. When loaded by the vehicle, these raised ridges were forced into the ground and created a “cookie cutter” appearance.

Conclusions

A venue hosting an event subjecting the playing surface to heavy vehicular traffic should utilize a minimum of two layers of ¾” plywood to resist compaction and soil displacement. However, the plywood should not be left down more than 3 consecutive days. If the playing surface is going to have lighter utility vehicle loads and foot traffic, a cover system like Terra Trak Plus or Supa-trac may be a better alternative, enabling the sports turf manager to leave the covers on field for longer periods of time.

Table 1.1. Traffic Vehicle Weight by Individual Tire and Subsequent Pressure Exerted on the Ground.

	Width (cm)	Length (cm)	Weight (kg)	Force (kg cm^{-2})	Force (lb in^{-2})
Front Right†	21.5	19.3	1179.3	2.84	40.4
Front Left	21.5	19.3	1170.2	2.82	40.1
Back Right	39.3	19.3	3302.1	4.35	61.9
Back Left	39.3	19.3	3311.2	4.36	62.0
Total			**8962.9**		

†The force exerted at each quadrant of the vehicle (right front, right rear, left front, left rear) was calculated by dividing the weight measured at each quadrant by the tire surface area in contact with the ground. The truck was equipped with dual rear tires. Therefore, the surface area of each tire was calculated individually and totaled for each quadrant.

Fig. 1.1. Enkamat Plus is a flexible, lightweight, black, highly porous material covered with a gray polyester fabric bonded to the top (overall thickness 0.80 in.).

Fig. 1.2. Enkamat Flatback is a flexible, lightweight, black, highly porous material made of interwoven nylon monofilaments with a thickness of 0.65 inches.

Fig. 1.3. Supa-Trac™ is a gray, semi-porous, interlocking panel system (each panel measures 38.0" × 11.0") with a waffled bottom made from copolymer polypropylene (overall thickness 1.4 in.).

Fig. 1.4. TerraTrak Plus™ is made from translucent, high-density polyethylene (HDPE) plastic. Individual panels measure 4 ft × 4 ft and have an overall thickness of 1.5 in. The panels lock together to form a gap free surface. The bottoms of each piece are completely flat.

Fig. 1.5. The loaded dump truck had a gross vehicle weight rating of 20,000 lbs. Ten passes were made over the covers on the day of covering and on the day covers were removed.

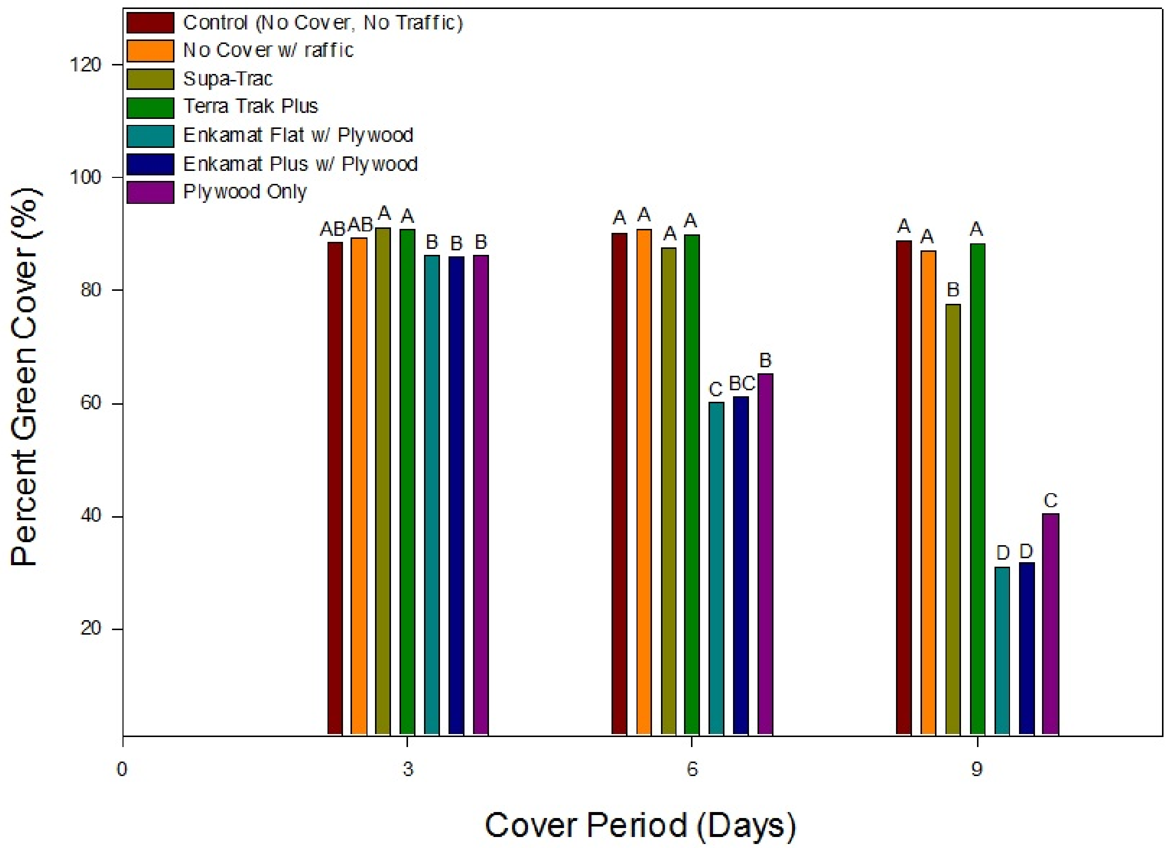

Fig. 1.6. The interaction of cover type and cover duration on percent green cover. Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

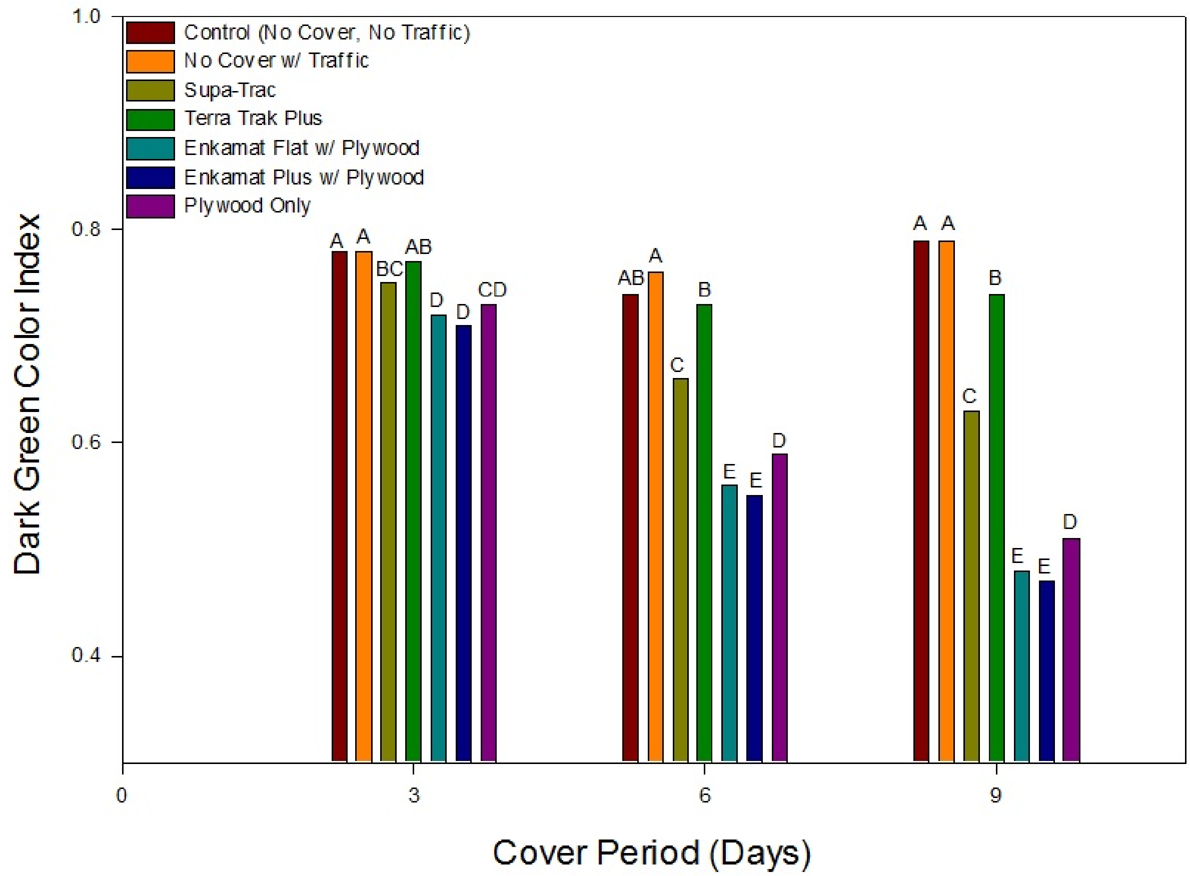

Fig. 1.7. The interaction of cover type and cover duration on dark green color index (DGCI). Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

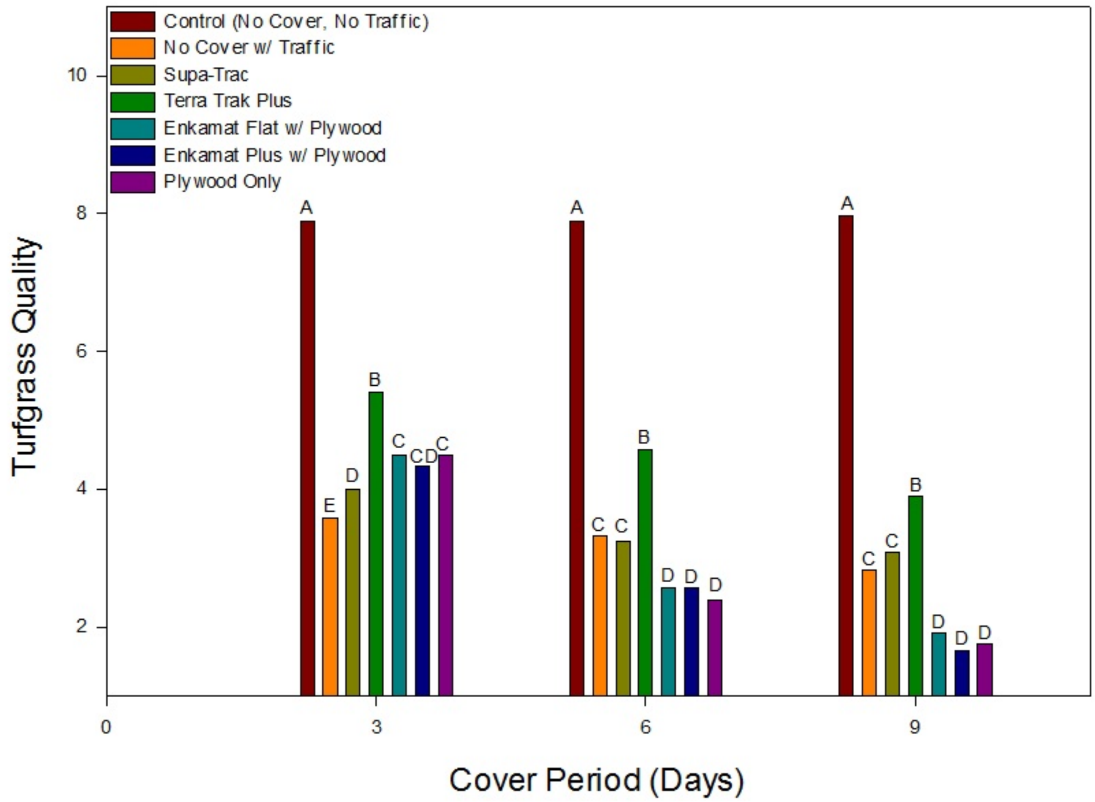

Fig. 1.8. The interaction of cover type and cover duration on turfgrass quality. Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

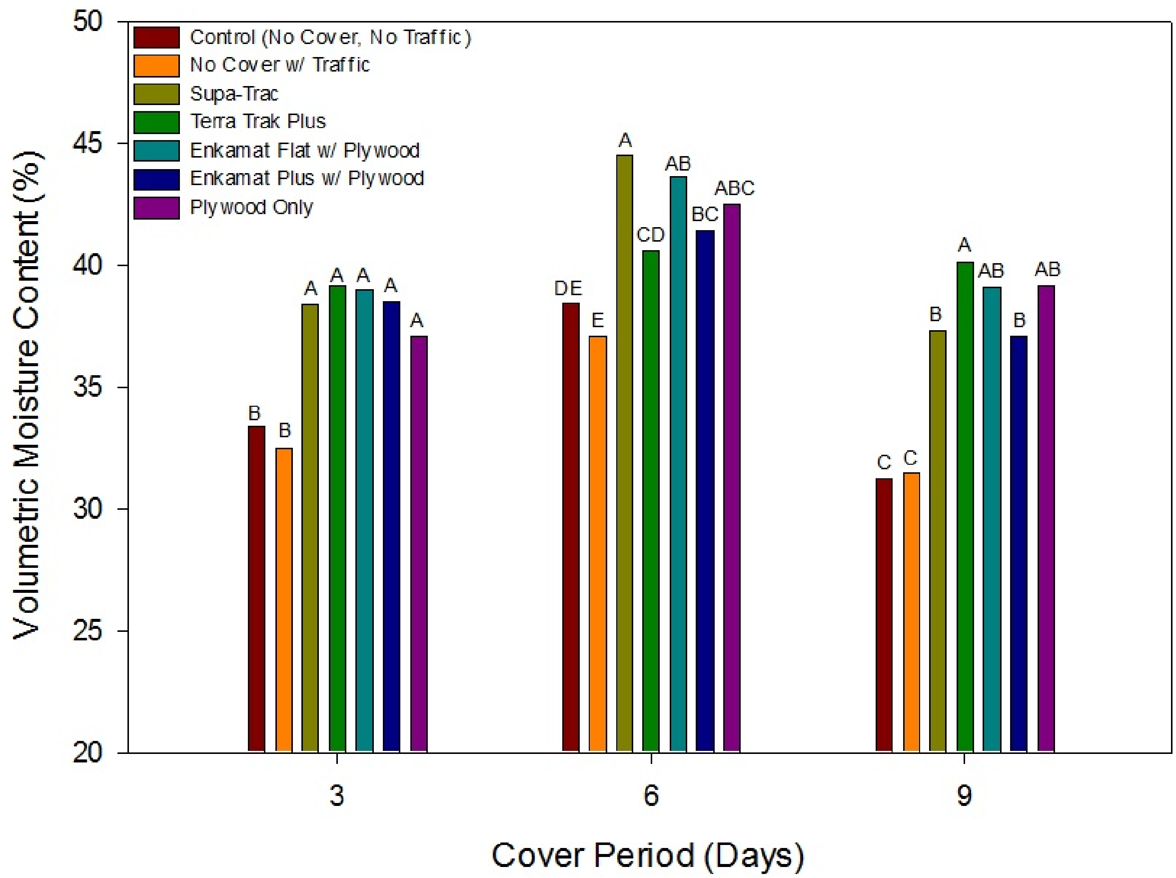

Fig. 1.9. The interaction of cover type and cover duration on volumetric moisture content (VMC). Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

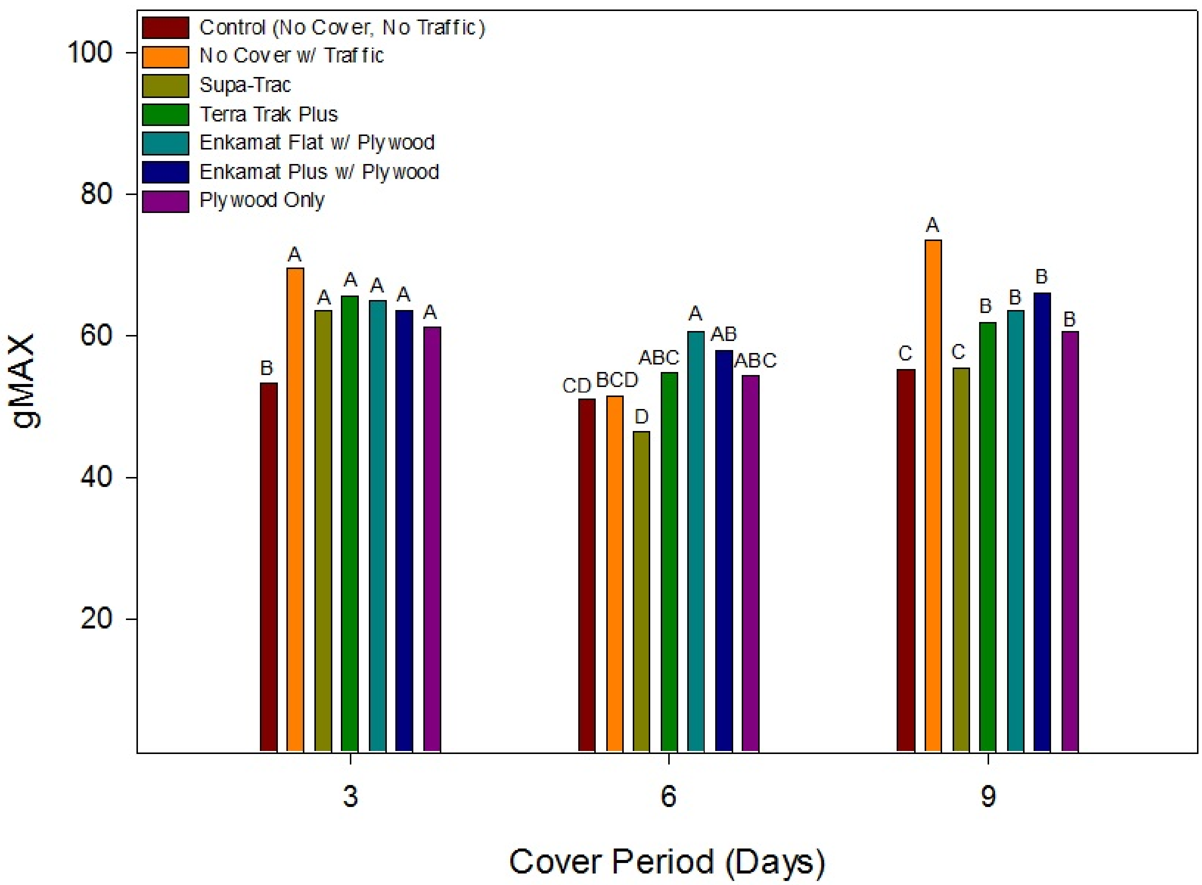

Fig. 1.10. The interaction of cover type and cover duration on surface hardness. Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

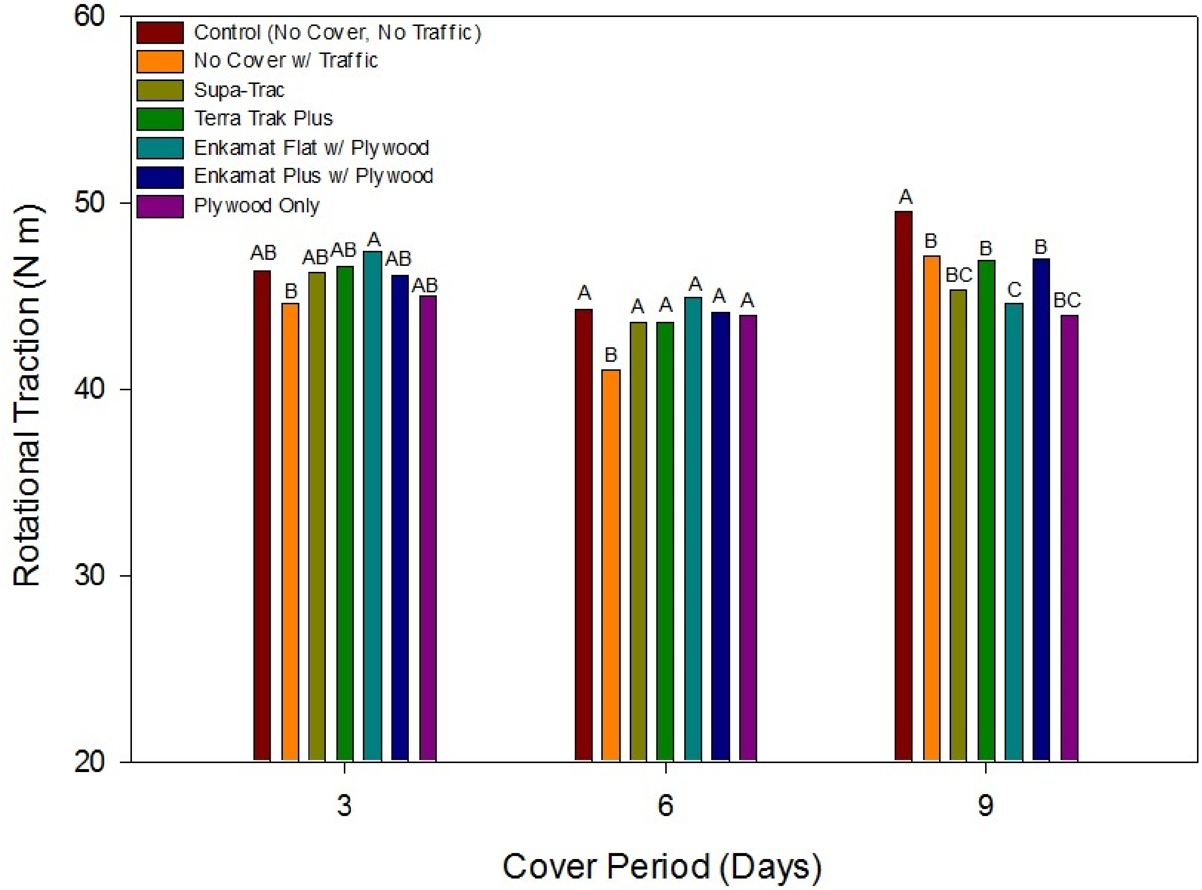

Fig. 1.11. The interaction of cover type and cover duration on rotational traction. Covers with the same letter within days are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

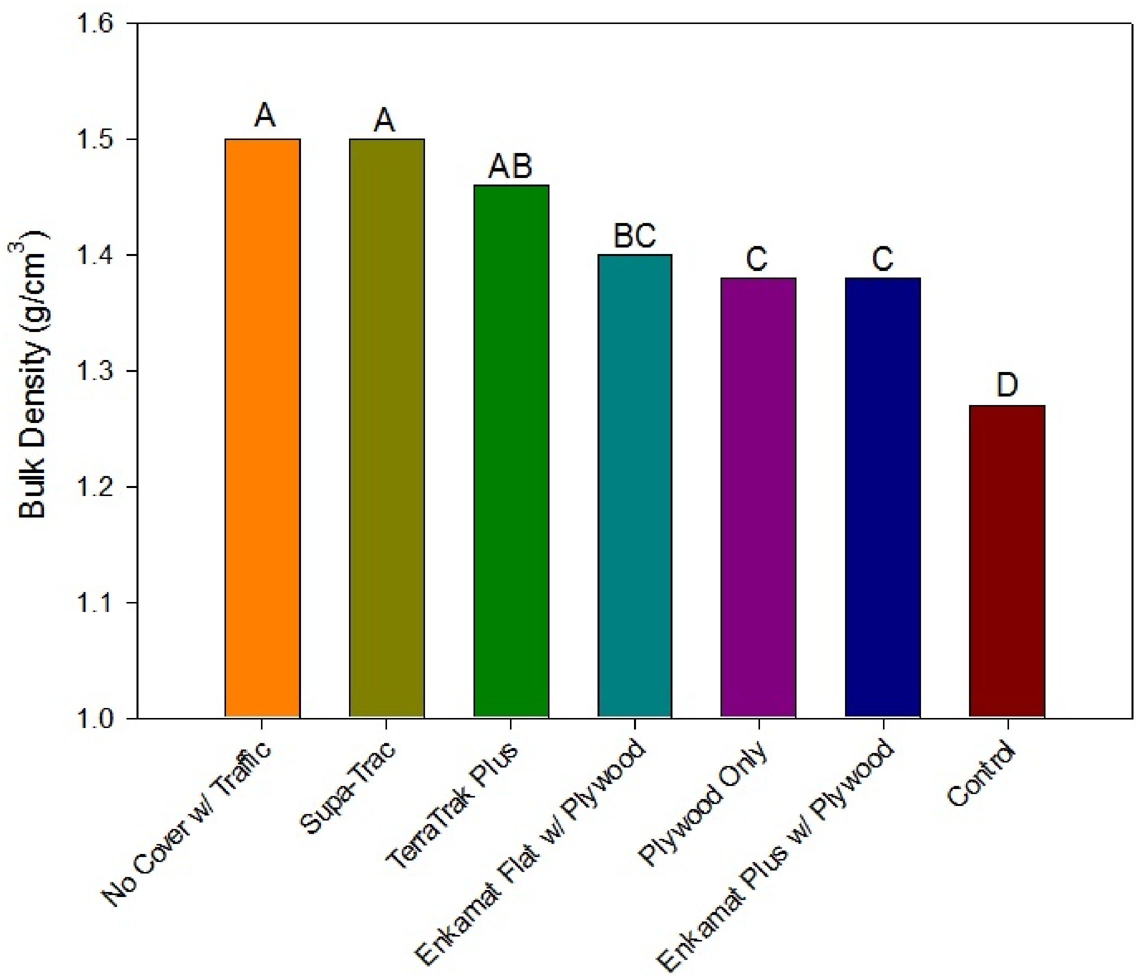

Fig. 1.12. The main effect of cover type on soil bulk density. Covers with the same letters are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

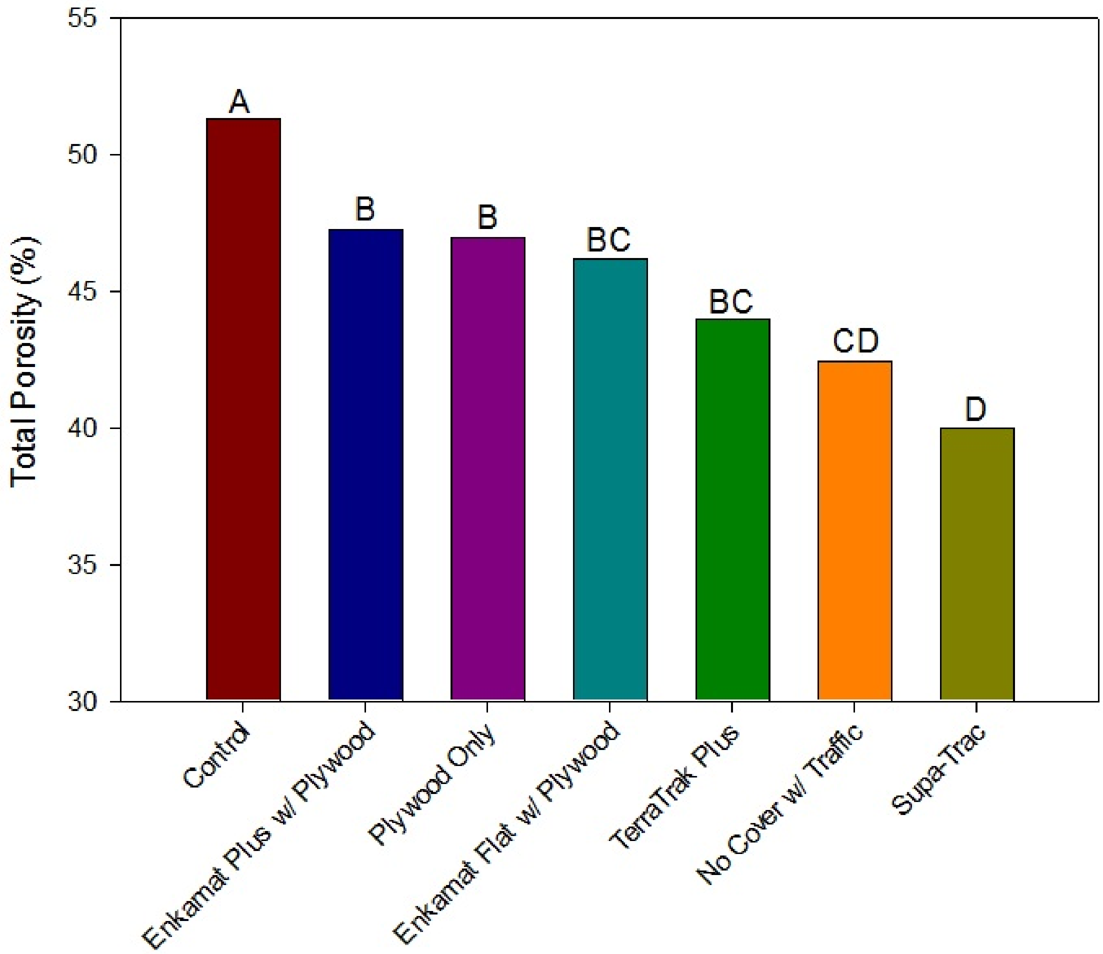

Fig. 1.13. The main effect of cover type on total porosity. Covers with the same letters are not significantly different (*$p \leq 0.05$*) according to Fisher's LSD test.

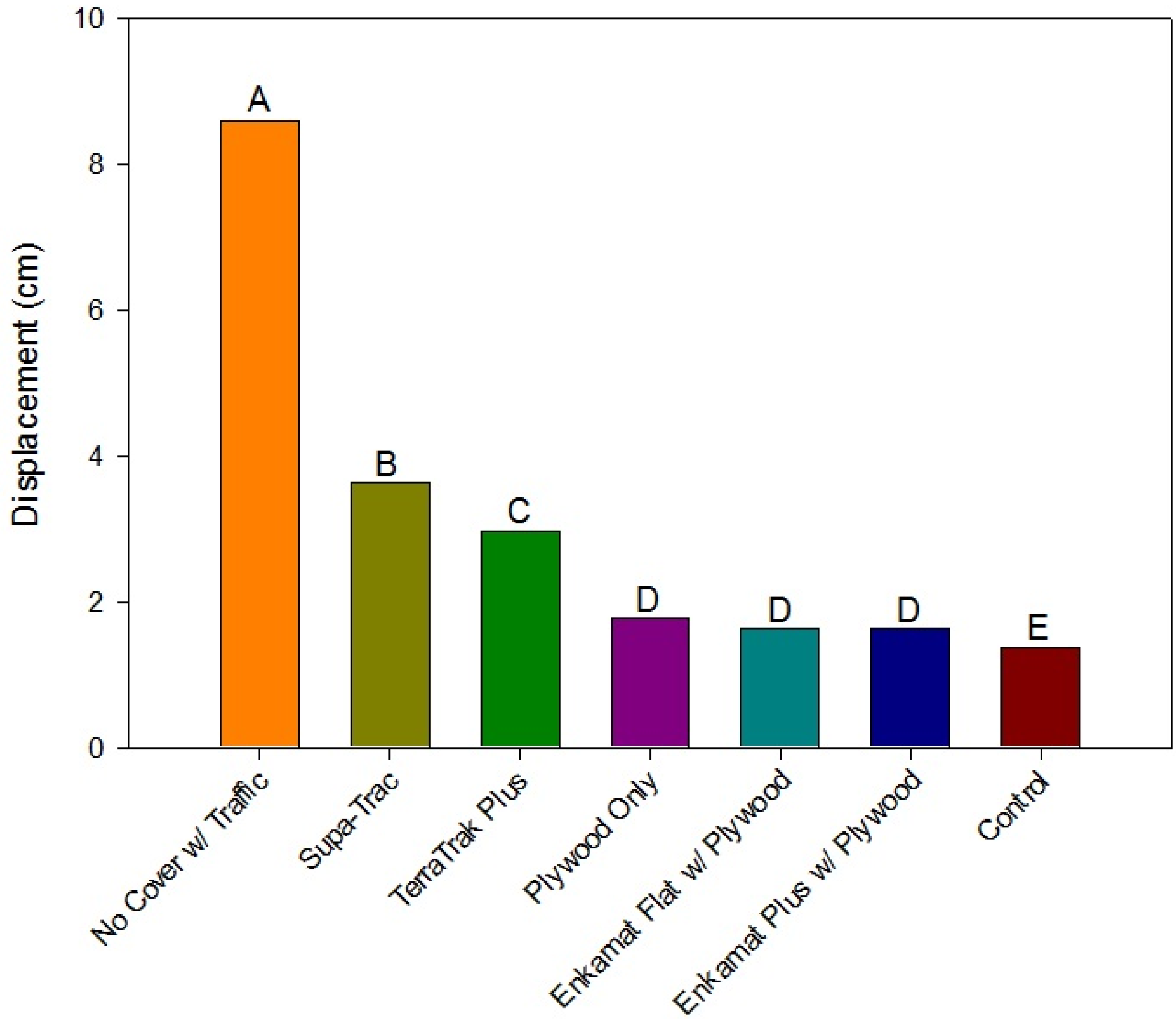

Fig. 1.14. The main effect of cover type on soil displacement. Covers with the same letters are not significantly different ($p \leq 0.05$) according to Fisher's LSD test.

Chapter 2

Leaf compost and sand topdressing effects on turfgrass performance and weed populations when applied to two soil types

Abstract

Currently, the research-based information regarding compost topdressing on athletic fields is very limited. The objectives of this research were to determine the effects of leaf compost and sand topdressing incorporated with core cultivation on turfgrass performance (turfgrass color, quality and percent green cover) and weed populations when applied to low and high organic matter soils. The study was arranged in a 2 × 2 × 3 (soil type × core cultivation × topdressing) factorial when the main plots were set out in a latin rectangle design nested within two soil types with six replications. Soil type had two levels; high organic matter soil and low organic matter soil. Core cultivation had two levels; yes and no. Topdressing had three levels: 1) leaf compost topdressing applied at 0.635 cm in the spring and fall, 2) sand topdressing applied at 0.635 cm in the spring and fall, and 3) no topdressing applied. The main plots (topdressing) were split by core cultivation. Simulated athletic field traffic was applied using a Cady Traffic Simulator during the fall to simulate a fall sports season. Leaf compost treatments consistently enhanced turfgrass color, turfgrass quality, and percent green cover when applied to both the low and high organic matter soils in this study. Crabgrass populations were reduced with the application of leaf compost topdressing regardless of soil type.

Introduction

Composts are derived from a variety of materials including manures, yard wastes, and municipal biosolids. These materials have been used as a soil amendment by mixing on or off-site prior to turfgrass establishment or as topdressing to established turfgrass areas. Topdressing is the process of surface applying a material to established turfgrass most commonly done with sand to promote smooth playing surfaces and manage organic matter accumulation on golf course greens and tees, as well as on highly maintained athletic fields. Recently, pressure to reduce pesticide use has increased interest in organic and/or synthetic pesticide-free management of golf courses, sports fields, and lawns. Additionally, the use of compost topdressing as part of an integrated pest management (IPM) program is becoming more popular in an effort to reduce the use of fertilizer and pesticides.

Incorporating compost prior to seeding increased turfgrass color and cover during the establishment of Kentucky bluegrass (Landschoot and McNitt, 1994; Linde and Hepner 2005). Monthly applications of sun-dried waste-water sludge increased turf color, quality, and clipping yield (Angle et al., 1981). Topdressing manure compost at 66 and 99 $m^3 ha^{-1}$ increased the overall quality of two cultivars of Kentucky bluegrass (*Poa pratensis* L.) by 10% during the growing season, enhanced color retention in the fall and increased spring green up (Johnson et al., 2006). Enhanced turfgrass establishment and growth on plots amended with sewage sludge compost have been attributed to the plant available nitrogen and phosphorus introduced to the seedbed with compost (Loschinkohl and Boehm, 2001). Topdressing of composted biosolids resulted in enhanced color and growth of tall fescue (*Festuca arundinacea* L.) and a mixed stand of Kentucky bluegrass and perennial ryegrass (*Lolium perenne* L.) for up to 32 days (Schuman et al., 1993). Applications of composted biosolids used as amendments at increasing rates, resulted

in a linear increase in tall fescue clipping yields and foliar N concentrations in both greenhouse and field studies (Sikora et al., 1980; Tester et al., 1982; Tester, 1989). A positive linear relationship has been established between the amount of N supplied by a composted biosolid amendment and the yield of perennial ryegrass grown in a greenhouse (Chen, 1997). Johnson et al., (2006) also concluded composted manure topdressing allowed the turfgrass to retain color in the fall and early winter and green up faster in the spring.

Compost applications have also been shown to reduce disease incidence and weed infestations in turfgrass stands. Poultry-cow manure compost were effective in reducing dollar spot (*Sclerotinia homeocarpa*) severity on creeping bentgrass *(Agrostis stolonifera* var. *palustris*) (Nelson and Craft, 1992). Multiple applications of compost made from feed stocks may reduce incidence and severity of dollar sport to levels at which chemical control may be reduced or eliminated for a significant portion of the season (Boulter et. al., 2002). Craft and Nelson (1996) suggested that enhanced turfgrass nutrition provided by composted turkey litter-sand topdressing mix may have aided in the suppression of Pythium root rot (*Pythium graminicola* Subramanian) on a creeping bentgrass putting green. Leaf rust severity was significantly lower on perennial ryegrass seeded on compost amended plots 6 to 9 weeks after seeding (Loschinkohl and Boehm, 2001). Mulching leaves regardless of genus (*Acer* or *Quercus*) into established turfgrass as a leaf litter disposal method will increase spring green-up and contribute to a reduction in common dandelion population (*Taraxacum offincinale)* (Kowalewski et al., 2009).

Few studies have assessed effects of compost topdressing on athletic fields. Topdressing athletic fields with spent mushroom substrate (SMS) has been evaluated showing many positive impacts such as an increase in percent ground cover after wear, decreased bulk density, increased water retention, and decreased surface hardness (McNitt et al., 2004). Johnson (2006) evaluated

the effects of spring and fall manure compost topdressing applications at four different rates on Kentucky bluegrass quality. Higher rates of application (66 and 99 m^3 ha^{-1}) resulted in significantly higher turfgrass quality. Repeated biosolid topdressing application has been shown to improve overall turfgrass quality under traffic conditions (Munoz et al., 2010). A few studies have evaluated different compost types applied as topdressing to playing surfaces, however, repeated leaf compost applications have not been evaluated on multiple soil types subjected to simulated traffic. Leaf compost is considered desirable since it's readily available and has low phosphorus content. Additionally, the effectiveness of core cultivation as an incorporation method for compost has not been thoroughly evaluated.

The objectives of this research were to determine the effects of leaf compost and sand topdressing incorporated with core cultivation on turfgrass performance (turfgrass color, quality, and percent green cover) and weed populations when applied to low and high organic matter soils.

Materials and Methods

This study was conducted at the University of Connecticut Plant Science Research and Education Facility located in Storrs, CT, during the 2010, 2011, and 2012 growing seasons. There were two soils used in the research area; a high organic matter soil classified as a Woodbridge loam/sandy loam (Coarse-loamy, mixed, active, mesic Aquic Dystudepts), with a pH of 6.1, 52% sand, 34% silt, 14% clay, and 6% organic matter by weight. The other soil was a sandy loam subsoil with a pH of 5.3, 64% sand, 23% silt, 13% clay, and less than 1% organic matter by weight. The study was performed on a mixed stand of Kentucky bluegrass '25% Award, 25% America, 25% Alpine, and 25% Northstar'. The study was arranged in a 2 x 2 x 3

(soil type × core cultivation × topdressing) factorial set out in a split plot design. The main plots were set out in a latin rectangle design with six replications nested within two soil types. Soil type had two levels; high organic matter soil and low organic matter soil. Core cultivation had two levels; yes and no. Topdressing had three levels: 1) leaf compost topdressing applied at 0.635 cm in the spring and fall, 2) sand topdressing applied at 0.635 cm in the spring and fall (Table 2.1), and 3) no topdressing applied. The main plots (topdressing treatments), 3.0 m × 3.0 m, were split by cultivation into two subplots (yes and no), 1.5 m × 3.0 m, at the end of the 2010 growing season. The cultivated treatments were core cultivated in two directions using a Ryan GreensAire II (Steve Willand Inc., Brookfield, CT) equipped with1.58 cm hollow core tines following compost topdressing. Plots were mowed twice per week with a 53 cm walk behind rotary mower (The Toro Company, Bloomington, MN) at 5.0 cm and clippings were returned. Plots were irrigated as needed to prevent moisture stress.

Construction

The research area was constructed during the spring of 2010. The native sandy loam soil (A Horizon) was completely excavated to a 30.5 cm depth, screened to 2.5 cm × 3.6 cm, and compacted back into the high organic matter (6% w/w) study area. A low organic matter sandy loam (<1% w/w), screened to 1.9 cm, was trucked in and compacted into the low organic matter study area. Plot areas were sodded with washed Kentucky bluegrass and core cultivated in two directions with 1.2 cm hollow core tines with 5 cm x 5 cm spacing to assist with sod establishment on May 11, 2010.

Topdressing Treatments and Fertility

During the first year of the study, topdressing treatments were applied on 16 June 2010 and 26 November 2010. Starter fertilizer (18-24-12, 9% ammoniacal nitrogen, 9% urea nitrogen, The Andersons, Maumee, Ohio) was applied on 25 May 2010 at a rate of 36.6 kg N ha^{-1}. Subsequent fertilizer applications derived from dried poultry waste, blood meal, feather meal and sulfate of potash (8-1-4) (North Country Organics, Bradford, VT) were applied at a rate of 49 kg N ha^{-1} from 22 June 2010 through 13 August 2010 every 21 days. Additional phosphorus applications were applied with a calcined bone meal product (0-16-0) (North Country Organics, Bradford, VT) at the rate of 22 kg P ha^{-1} per application on 13 August. Total nutrient applications from fertilizer sources for the growing season were as follows; 231.89 kg N ha^{-1}, 56 kg P ha^{-1}, and 101 kg K ha^{-1}. The nutrients applied from each leaf compost application were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

During the second year of the study, treatments were applied on 27 May 2011 and 2 December 2011. Pelletized dolomitic limestone was applied on 25 May at a rate of 2197 kg ha^{-1}. An initial application of corn gluten (9-0-0) (Harrington's Organic Land Care, Bloomfield CT) was applied at a rate of 98 kg N ha^{-1} on 10 May 2011. Subsequent fertilizer applications derived from dried poultry waste, blood meal, feather meal and sulfate of potash (8-2-4) (Macky's Home, Farm, Pet, and Wild Bird Supply, Willimantic, CT) were applied at a rate of 49 kg N ha^{-1} on 21 July 2011 and 25 August 2011. An additional phosphorus application was applied on 21 July 2011 using 0-16-0 (North Country Organics, Bradford, VT) at a rate of 22 kg P ha^{-1} Total nutrient applications from fertilizer sources for the growing season were as follows; 195 kg N ha^{-1},32 kg P ha^{-1}, and 41 kg K ha^{-1}. Total nutrient applications from leaf compost were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

During the third year of the study, treatments were applied on 31 May 2012 only. Pelletized dolomitic limestone was applied on 29 May at a rate of 2197 kg ha $^{-1}$. An initial application of fertilizer corn gluten Meal (9-0-0) (Macky's Home, Farm, Pet, and Wild Bird Supply, Willimantic, CT) was applied at a rate of 98 kg ha^{-1} on 15 May 2012. Subsequent fertilizer applications were applied from 6 July 2012 through 30 August 2012 using (8-2-4) (Macky's Home, Farm, Pet, and Wild Bird Supply) (Willimantic, CT) every 21 days at a rate of 24 kg N ha^{-1}. Additional phosphorus (0-16-0) (North Country Organics, Bradford, VT) was also applied on 13 August 2012 at a rate of 22 kg P ha^{-1}. Total nutrient applications from fertilizer sources for the growing season were as follows; 193 kg N ha^{-1}, 32 kg P ha^{-1}, and 41 kg K ha^{-1}. Total nutrient applications from leaf compost were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

Traffic Simulation

Traffic simulation was conducted using a Cady Traffic Simulator, a modified walk-behind core cultivation unit (Henderson et al., 2005). Each traffic event consisted of two forward passes over the entire study in different directions. The traffic in 2010 was conducted from 15 September to 29 November, totaling 25 traffic events. The traffic in 2011 went from 29 August to 18 November, totaling 27 traffic events. The traffic in 2012 went from 3 September to 21 November, totaling 28 traffic events. The target was three events per week, with weather and mechanical issues forcing occasional alterations in the schedule.

Data Collection

Data collection included turfgrass performance (percent cover, turfgrass color, quality, crabgrass and broad leaf weed counts). Digital image analysis was utilized in assessing turf color and cover (Karcher and Richardson, 2005). Controlled light conditions were provided through the use of a light box. Images were scanned using Sigma Scan Software (Cranes Software International Limited, Chicago, IL) using the following threshold values; hue=55-125 and saturation=10-100. The Dark Green Color Index (DGCI) and percent cover were calculated based on hue, saturation and brightness values (Karcher and Richardson, 2003; Karcher and Richardson, 2005). Turfgrass quality was rated biweekly using a visual rating scale of 1 to 9, where 1=brown/dead turf; 6=minimum acceptable color/quality; and 9=optimum quality or dark green color. Weed count data was collected once each month during the growing season. Weed count data were obtained on a whole plot basis for both crabgrass (*Digitaria*) and broadleaf weeds. In 2010, broadleaf weed counts were taken from September to November and crabgrass counts were only taken in September. The counts for 2011 and 2012 were taken once per month from June to September.

Statistical Analysis

Analysis of variance was used to test for significant ($p \leq 0.05$) differences between treatments using the MIXED and GLM procedures of the SAS statistical software v. 9.3 (SAS Institute Inc., Cary, NC). The 2010 growing season was analyzed separately from the other years because the core cultivation treatments had not been imposed during the establishment year in 2010. Beginning in 2011 and continuing through 2012, core cultivation or no cultivation was included as subplot treatments. Data from the 2011 and 2012 growing seasons were combined,

since topdressing and cultivation typically have cumulative effects and there was an interest to see if any cumulative effects were present from these treatments. When data were combined for 2011 and 2012, years were treated as a repeated measure since topdressing and cultivation was done on a yearly basis. Where differences between treatments using appropriate F-tests showed significance, mean separations were conducted using Fisher's LSD test with a 0.05 probability level.

Results

Dark Green Color Index

2010

Differences in DGCI were primarily observed as an overall soil effect during the 2010 growing season (Table 2.3). The high organic matter soil consistently showed significantly higher DGCI when compared with the low organic matter soil. Plots receiving leaf compost topdressing showed a significant increase in DGCI compared to the untreated control and sand treated plots regardless of soil type by the end of June. The compost main effect dissipated through most of the fall. By late November, plots receiving compost had higher DGCI values compared to the sand and untreated control in the low organic matter soil only (Fig. 2.1).

2011-2012

During the 2011 and 2012 growing season, DGCI differences were mainly observed as soil, treatment, and year main effects (Table 2.4). Generally, the high organic matter soil and plots receiving compost exhibited higher turfgrass color values. The 2011 growing season produced significantly higher color values than the 2012 growing season. However, many of

these main effects need to be interpreted carefully since significant interactions were also observed. A soil × treatment, treatment× cultivation, year × treatment, and year × soil interaction were observed during the 2011-2012 growing seasons.

DGCI differences in the soil × treatment interaction show plots receiving compost had higher DGCI values than the sand or untreated control regardless of soil type (Fig. 2.2). The sand topdressed and untreated control plots were not significant in the high organic matter soil, however in the low organic matter soil, the sand topdressed plots had significantly higher DGCI values than the untreated control. The year × treatment interaction shows plots treated with leaf compost topdressing retained significantly higher DGCI values than the untreated control and sand topdressed plots regardless of year (Fig. 2.3). The 2011 growing season did not show any statistical differences between the sand treated plots and the untreated control, but during the 2012 growing season, the sand topdressed plots had significantly less DGCI values than the untreated control. The high organic matter soil consistently retained significantly darker green color than the low organic matter soil regardless of year (Fig. 2.4). The differences between soil types were greater during the 2012 growing season than the 2011 growing season. The treatment × cultivation interaction was inconsistent (data not shown). Sand topdressed plots that received cultivation retained significantly less DGCI than plots that did not receive cultivation; however there were no differences between cultivated and non-cultivated plots that received compost topdressing. The untreated control plots that received cultivation retained significantly more dark green color than plots that did not receive cultivation.

Percent Green Cover

2010

Percent green cover differences were observed as an overall soil and treatment main effects during the 2010 growing season (Table 2.5). The high organic matter soil generally had significantly higher percent green cover when compared to the low organic matter soil. The plots that received compost topdressing had significantly higher percent green cover when compared to the untreated control plots during the 2010 growing season.

2011-2012

Cover differences observed during the 2011-2012 growing seasons were primarily observed as treatment, soil, cultivation, and year main effects (Table 2.4). Overall, the high organic matter soil retained greater percent green cover than the low organic matter soil. Leaf compost applications resulted in higher percent green cover compared to sand and the untreated control. Cultivation main effects were also observed showing slightly less percent green cover in the cultivated treatments, while the 2011 growing season retained higher percent green cover than the 2012 growing season. Several interactions were also significant including soil × treatment, soil × cultivation and year × soil. A soil × treatment interaction was observed showing the plots receiving compost topdressing had higher percent green cover values compared to the sand topdressed plots and the untreated control plots regardless of soil type (Fig. 2.5). The interaction shows the differences between the sand topdressed plots and untreated control plots are greater on the low organic matter soil compared to the high organic matter soil. A soil × cultivation interaction was observed showing plots receiving core cultivation on the low organic matter only soil had significantly lower percent green cover compared to plots that did not

receive core cultivation on the low organic matter soil only (Fig. 2.6). The year × soil interaction consistently showed that the high organic matter soil retained significantly more percent cover than the low organic matter soil regardless of year and the differences between treatments were greater in the 2011 growing season compared to 2012 growing season (Fig. 2.7).

Turfgrass Quality

2010

In 2010 turfgrass quality differences were primarily observed as soil and treatment main effects. A soil main effect was observed on four out of the eight days data were collected (Table 2.6). On these dates, the high organic matter soil had significantly higher quality ratings than the low organic matter soil. A topdressing treatment main effect was observed on 3 out of the 8 dates data were collected. On these dates, plots that received leaf compost topdressing had higher quality ratings compared to plots that received sand topdressing and the untreated control.

2011-2012

During the 2011-2012 growing seasons, soil, treatment, and year main effects were observed (Table 2.4). The high organic matter soil had significantly higher quality ratings than the low organic matter soil and plots receiving leaf compost topdressing had significantly higher quality ratings compared to the untreated control and sand topdressed plots. A soil × treatment interaction was observed showing plots receiving leaf compost topdressing had significantly higher quality ratings compared to the untreated control and sand topdressed plots regardless of soil type (Fig. 2.8). Differences between treatments for the soil × treatment interaction were greater in the low organic matter soil compared to the high organic matter soil. A year × soil and

a year × treatment interaction was observed as well. The high organic matter soil had significantly higher quality ratings than the low organic matter soil regardless of year and had greater differences during the 2011 growing season compared to the 2012 growing season (Fig. 2.9). The year × treatment interaction showed the high organic matter soil had greater differences between treatments during the 2011 growing season compared to the 2012 growing season, and plots receiving leaf compost topdressing had higher visual quality ratings compared to plots that received sand topdressing and the untreated control regardless of year (Fig. 2.10).

Crabgrass Counts

2010

Due to the study being in its initial stage, crabgrass counts were only taken twice during the 2010 growing season. Results show a significant treatment main effect and a significant soil × treatment interaction on both dates (Table 2.7). A significant soil main effect was observed on 19 September only. Plots that received compost topdressing had significantly higher crabgrass populations when compared to the untreated control and sand topdressed plots on 9 Sept. On 19 September, compost treatments had significantly higher crabgrass populations when compared to the untreated control, but was not different from the sand topdressed plots. The soil × treatment interaction showed inconsistent differences during the 2010 growing season (data not shown). Plots that received leaf compost topdressing had significantly more crabgrass than all other treatments regardless of soil type on 9 September. The differences between the compost topdressed plots and the sand topdressed plots were greater on the high organic matter soil compared to the low organic soil. However, on 19 September, plots receiving leaf compost topdressing had significantly higher crabgrass populations than the untreated control, but were

not statistically different from plots receiving sand topdressing on the high organic matter soil only.

2011-2012

During the 2011-2012 growing season, crabgrass counts had overall treatment and year main effects (Table 2.4). Plots that received compost topdressing had significantly less crabgrass populations when compared to the untreated control and sand topdressed plots while 2011 had lower crabgrass populations than 2012. A year × soil interaction was also observed where the high organic matter soil had significantly higher crabgrass populations than the low organic matter soil during 2011 only (Fig. 2.11).

Broadleaf Weed Counts

2010

Differences in broadleaf weed counts were observed as an overall soil effect during the 2010 growing season (Table 2.8). Results show the high organic matter soil had a significantly higher amount of broadleaf weeds when compared to the low organic matter soil through September and October.

2011-2012

During the 2011-2012 growing seasons, an overall year main effect was observed (Table 2.4). During 2012, there was a significantly higher amount of broadleaf weeds compared to 2011. A year × soil interaction was also observed showing the high organic matter soil having significantly more broadleaf weeds than the low organic matter soil during 2012 only (Fig. 2.12).

Discussion

Leaf compost topdressing applications significantly improved turfgrass color, percent green cover, and turfgrass quality during all three years of the study. Plots receiving leaf compost topdressing generally had better color and greater percent green cover than plots receiving sand topdressing or the untreated control regardless of soil type and year. Increased color and cover as a result of compost topdressing have been reported in previous research (Landschoot and McNitt, 1994; Hepner, 2005). Similar effects have also been reported where mulching maple or oak leaves into the turf canopy resulted in increased spring green-up (Kowalewski et al., 2009). Composted manure topdressing allowed the turf to retain better color in the late fall and early winter and green up faster in the spring (Johnson, 2006). The enhanced color and cover response associated with compost applications are most likely due to the additional nutrients applied to the turfgrass through the compost applications, most notably nitrogen and phosphorus.

Plots receiving leaf compost topdressing also had higher quality ratings across all three growing seasons. The nutrients applied with the leaf compost topdressing combined with the nutrients from fertilizer treatments enhanced the color, cover, and quality of the compost treated plots compared to the sand topdressing treatments or the untreated control, regardless of soil type and year. Repeated compost topdressing applications have also been reported to improve overall turfgrass quality under traffic conditions (Munoz et al. 2010; Johnson et al. 2006).

Crabgrass populations were reduced by leaf compost applications when the data was combined over the last two years of the study. The decrease in crabgrass populations is most likely due to the increased nitrogen added by the compost improving turfgrass density and possibly the weed free compost covering the weed seed in the soil. Applying compost to the turf surface may have inhibited the germination of crabgrass seeds that were already in the soil.

Conclusions

Based on these results, the benefits of leaf compost applications to athletic fields are fairly definitive and include enhanced color, higher percent green cover retention under trafficked conditions, higher turfgrass quality and reduced crabgrass populations. However, given the rates of leaf compost applied in this study and the frequency of application, the excessive level of nitrogen and phosphorus applied mainly became a significant concern. The potential impact of reducing both the rates and frequency of leaf compost application needs additional research.

Table 2.1. Chemical characteristics, physical characteristics and maturity level of leaf compost topdressing material.

	Chemical Characteristics						Physical Characteristics		Maturity
Parameter	pH	Soluble Salts (mmhos cm^{-1})	N (%)	P (%)	K (%)	C:N Ratio	Organic matter (g kg^{-1})	Moisture Content (%)	Respirometry (mg CO_2-C/g*)
Leaf Compost	7.3	0.92	0.88	0.14	0.37	15.4	263	46.4	1.4 †

* mg CO_2-C/g organic matter/day – Respirometry(CO_2 evolution) provides a measurement of the relative microbial activity in a compost. Therefore, this can be used as an estimate of compost stability.

† Interpretive index from the U.S. Compost Council Test Methods, <2 = Very Stable – Well cured compost, no continued decomposition, no odors, 2-8 = Stable – cured compost, odor production not likely, minimal impact on soil carbon and nitrogen dynamics

Table 2.2. Characteristics of sand topdressing compared to USGA recommendations.

	Soil Separate %				% Retained					
Treatment	**Sand**	**Silt**	**Clay**	**No. 10 Gravel 2 mm**	**No. 18 VCS 1 mm**	**No. 35 CS 0.5 mm**	**No. 60 MS 0.25 mm**	**No. 100 FS 0.15 mm**	**No. 140 VFS 0.10 mm**	**No. 270 VFS 0.05 mm**
Coarse Sand (AA Will Mat. 2mm)	99.5	0.0	0.4	0.1	11.0	31.5	42.0	13.0	1.6	0.4
USGA Rec. for Putting Green Const		**≤ 5%**	**≤ 3%**	**≤ 3% Gravel ≤ 10% Combined**		**≥ 60%**		**≤ 20%**	**≤ 5%**	

Table 2.3. Effect of soil type and topdressing source on Dark Green Color Index values†, 2010.

Main effects	15 June	30 June	9 Sept	30 Sept	7 Oct	19 Oct	9 Nov	30 Nov
Soil								
High	0.78 a‡	0.72 a	0.77 a	0.78 a	0.75 a	0.71 a	0.65 a	0.62 a
Low	0.77 a	0.68 b	0.72 b	0.67 b	0.68 b	0.64 b	0.56 b	0.49 b
Treatment (Treat)								
None	0.77 a	0.68 c	0.75 ab	0.73 a	0.71 a	0.68 a	0.61 a	0.55 b
Sand	0.77 a	0.69 b	0.74 b	0.73 a	0.71 a	0.67 a	0.61 a	0.56 b
Compost	0.77 a	0.73 a	0.75 a	0.72 a	0.72 a	0.68 a	0.61 a	0.57 a
Variation source				ANOVA				
Soil	NS¶	**	**	***	***	***	**	***
Treat	NS	***	*	NS	NS	NS	NS	**
Soil × Treat	NS	NS	NS	NS	NS	NS	**	*

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
¶NS, not significant.
† Dark Green Color Index (DGCI), the greater the number the darker the color green.
‡Means in a column followed by the same letter are not significantly different.

Table 2.4. Effect of soil type, cultivation, year, and topdressing source on turfgrass performance averaged across dates, 2011-2012.

Main effects	DGCI†	% Green	Quality#	Crabgrass m^{-2}††	BL Weeds m^{-2}
Soil					
High	0.63 a‡	69.38 a	4.23 a	42.22 a	62.98 a
Low	0.57 b	56.66 b	3.60 b	39.82 a	43.51 a
Cultivation (Cult)					
Yes	0.60 a	62.44 b	3.91 a	41.69 a	48.73 a
No	0.60 a	63.59 a	3.91 b	40.35 a	57.77 a
Year					
2011	0.62 a	67.64 a	4.89 a	37.60 b	4.41 b
2012	0.58 b	58.40 b	2.92 b	44.44 a	102.09 a
Treatment (Treat)					
None	0.59 b	60.50 b	3.73 c	47.30 a	52.82 a
Sand	0.58 c	59.47 b	3.84 b	48.35 a	55.55 a
Compost	0.60 a	59.08 a	4.18 a	27.41 b	51.38 a
Variation source			ANOVA		
Treat	***	***	***	***	NS
Soil	***	***	***	NS	NS
Soil × Treat	***	*	***	NS	NS
Cult	NS¶	*	NS	NS	NS
Treat × Cult	*	NS	NS	NS	NS
Soil × Cult	NS	*	NS	NS	NS
Soil*Treat*Cult	NS	NS	NS	NS	NS
Year	***	***	***	***	***
Year × Treat	*	NS	***	NS	NS
Year × Soil	***	***	***	**	*
Year × Soil × Treat	NS	NS	*	NS	NS
Year × Cult	NS	NS	NS	NS	NS
Year × Treat × Cult	NS	NS	NS	NS	NS
Year × Soil × Cult	NS	NS	NS	NS	NS
Year × Soil × Treat ×	NS	NS	NS	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
† Dark Green Color Index (DGCI), the greater the number the darker the color green.
‡Means in a column followed by the same letter are not significantly different.
¶NS, not significant.
§ Percent cover was calculated using Sigma Scan software; # of green pixels compared to total # of pixels.
# Quality ratings: 1 = dead turf; 6 = minimum acceptable quality; 9 = optimum quality.
†† Counts were made on a whole plot basis.
‡‡ Counts were made on a whole plot basis.

Table 2.5. Effect of soil type and topdressing source on percent green cover values†, 2010.

Main effects	15 June	30 June	9 Sept	24 Sept	7 Oct	19 Oct	9 Nov	30 Nov
Soil								
High	93.07 a‡	73.39 a	77.16 a	78.36 a	82.93 a	82.46 a	69.89 a	50.07 a
Low	92.21 a	69.91 b	77.66 a	74.26 b	74.78 b	73.12 b	53.65 b	29.32 b
Treatment (Treat)								
None	92.67 a	69.33 b	77.16 a	76.16 a	77.84 c	76.56 b	59.65 b	37.01 b
Sand	92.65 a	71.67 a	76.81 a	76.32 a	78.77 b	77.51 b	61.90 ab	39.91 a
Compost	92.59 a	73.96 a	78.26 a	76.49 a	79.95 a	79.29 a	63.77 a	42.18 a
Variation source				ANOVA				
Soil	NS¶	*	NS	*	**	**	**	***
Treat	NS	**	NS	NS	***	**	*	**
Soil × Treat	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
¶NS, not significant.
† Percent cover was calculated using Sigma Scan software; # of green pixels compared to total # of pixels.
‡Means in a column followed by the same letter are not significantly different.

Table 2.6. Effect of soil type and topdressing source on turfgrass quality†, 2010.

Main effects	2 July	9 Sept	23 Sept	7 Oct	19 Oct	9 Nov	18 Nov	30 Nov
Soil								
High	4.61 a‡	7.66 a	6.00 a	6.61 a	6.33 a	4.33 a	3.00 a	2.00 a
Low	4.16 a	7.00 b	6.00 a	5.61 b	4.44 b	3.22 b	3.00 a	2.00 a
Treatment (Treat)								
None	4.41 a	7.41 a	6.00 a	5.91 b	5.25 b	3.50 b	3.00 a	2.00 a
Sand	4.41 a	7.33 a	6.00 a	6.00 b	4.91 b	3.50 b	3.00 a	2.00 a
Compost	4.31 a	7.25 a	6.00 a	6.41 a	6.00 a	4.33 a	3.00 a	2.00 a
Variation source				ANOVA				
Soil	NS¶	*	NS	***	***	*	NS	NS
Treat	NS	NS	NS	*	***	***	NS	NS
Soil × Treat	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
¶NS, not significant.
† Quality ratings: 1 = dead turf; 6 = minimum acceptable quality; 9 = optimum quality.
‡Means in a column followed by the same letter are not significantly different.

Table 2.7. Effect of soil type and topdressing source on crabgrass counts† 2010.

Main effects	9 Sept	19 Sept
Soil	-------------------- Crabgrass plants m^{-2}	--------------------
High	1.63 a‡	1.29 a
Low	0.61 a	0.21 b
Treatment (Treat)		
None	0.77 b	0.52 b
Sand	0.97 b	0.83 a
Compost	1.62 a	0.89 a
Variation source	ANOVA	
Soil	NS¶	***
Treat	***	**
Soil × Treat	**	*

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
¶NS, not significant.
†Counts were made on a whole plot basis.
‡Means in a column followed by the same letter are not significantly different.

Table 2.8. Effect of soil type and topdressing source on broadleaf weed counts† 2010.

Main effects	Sept 9	Sept 19	Oct 19	Nov 18
Soil	-------------------- Broadleaf Weeds m^{-2} ---------------------			
High	0.53 a‡	0.70 a	0.005 a	0.05 a
Low	0.01 b	0.03 b	0.00 b	0.00 a
Treatment (Treat)				
None	0.22 a	0.35 a	0.08 a	0.03 a
Sand	0.24 a	0.30 a	0.10 a	0.03 a
Compost	0.34 a	0.44 a	0.05 a	0.00 b
Variation source		ANOVA		
Soil	***	**	*	NS
Treat	NS¶	NS	NS	*
Soil × Treat	NS	NS	NS	*

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
¶NS, not significant.
†Counts were made on a whole plot basis.
‡Means in a column followed by the same letter are not significantly different.

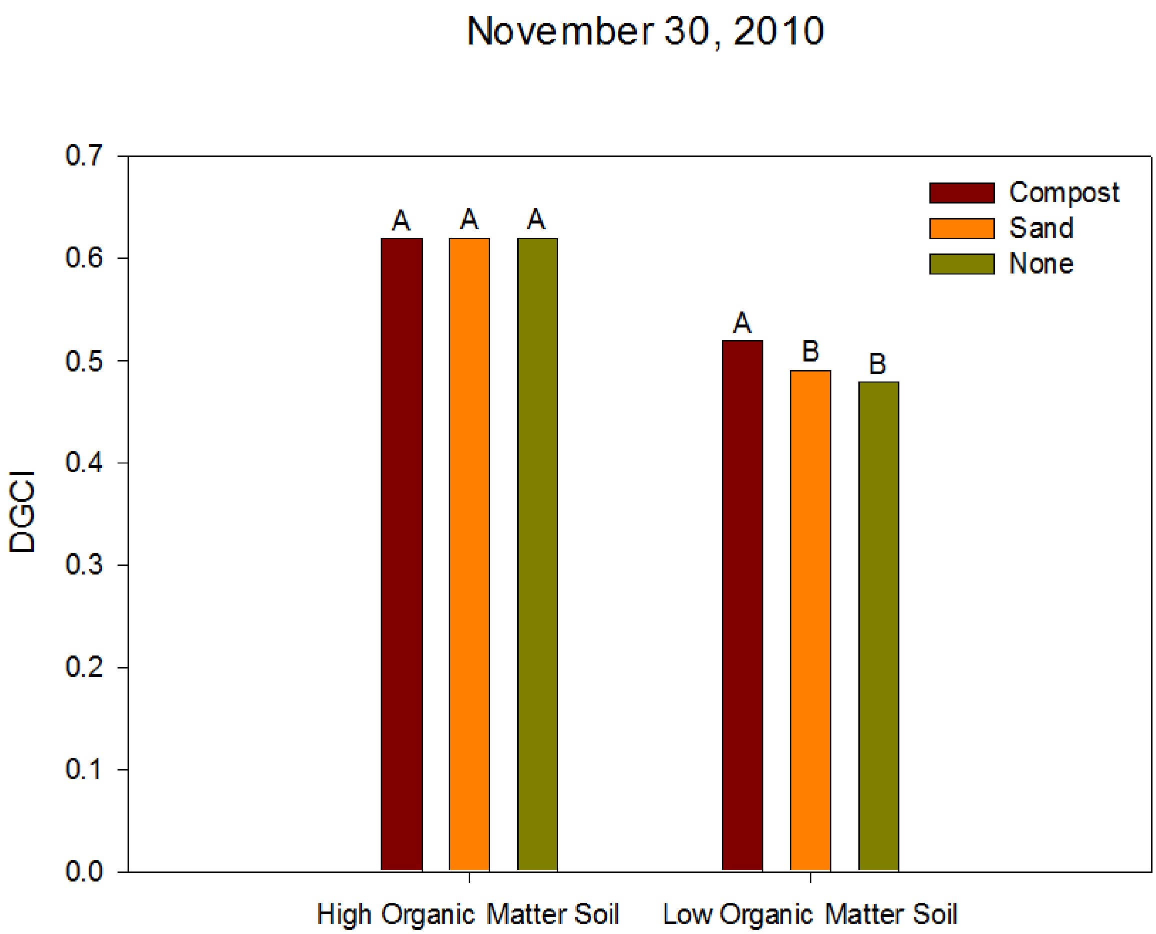

Fig. 2.1. The interaction effect of soil type and topdressing source on Dark Green Color Index (DGCI) when applied to two soils. November 20, 2010. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

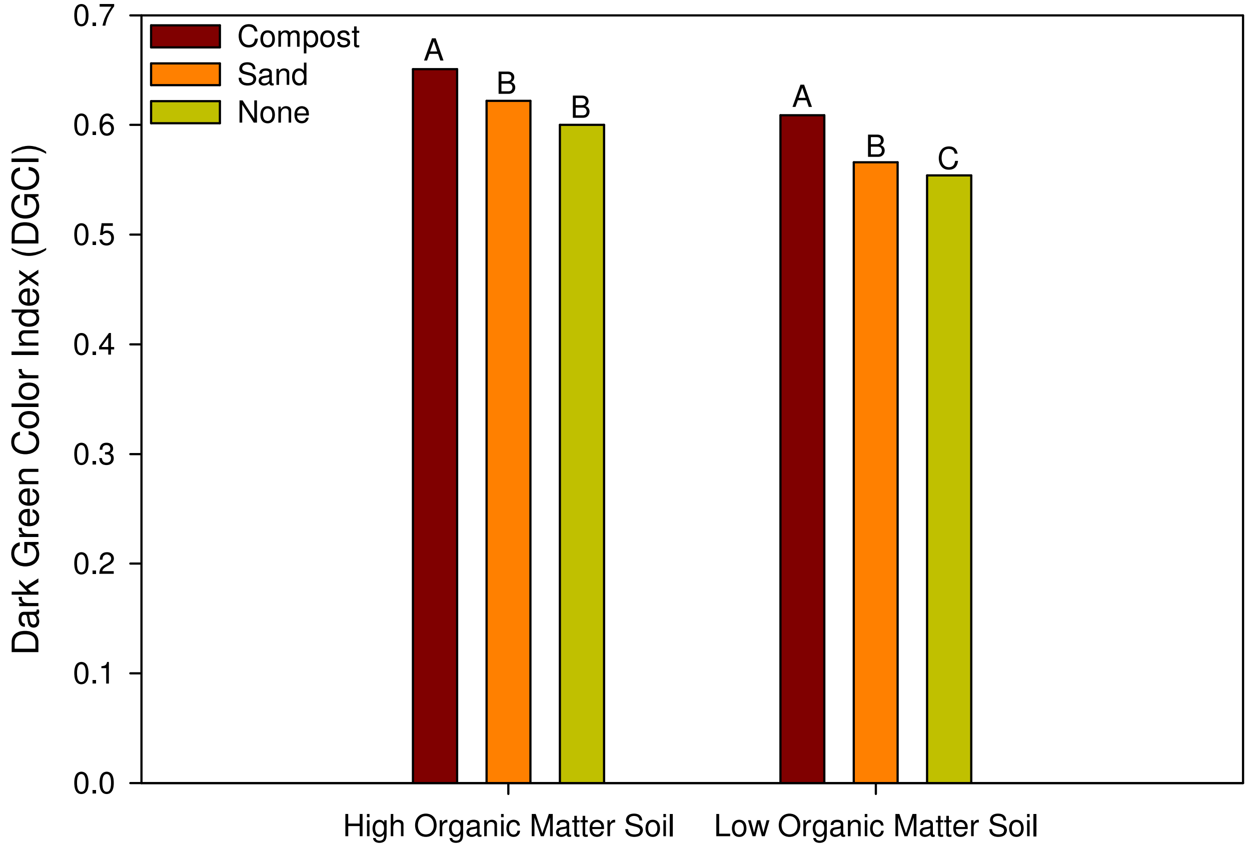

Fig. 2.2. The interaction effect of soil type and topdressing source on Dark Green Color Index (DGCI) when applied to two soils, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

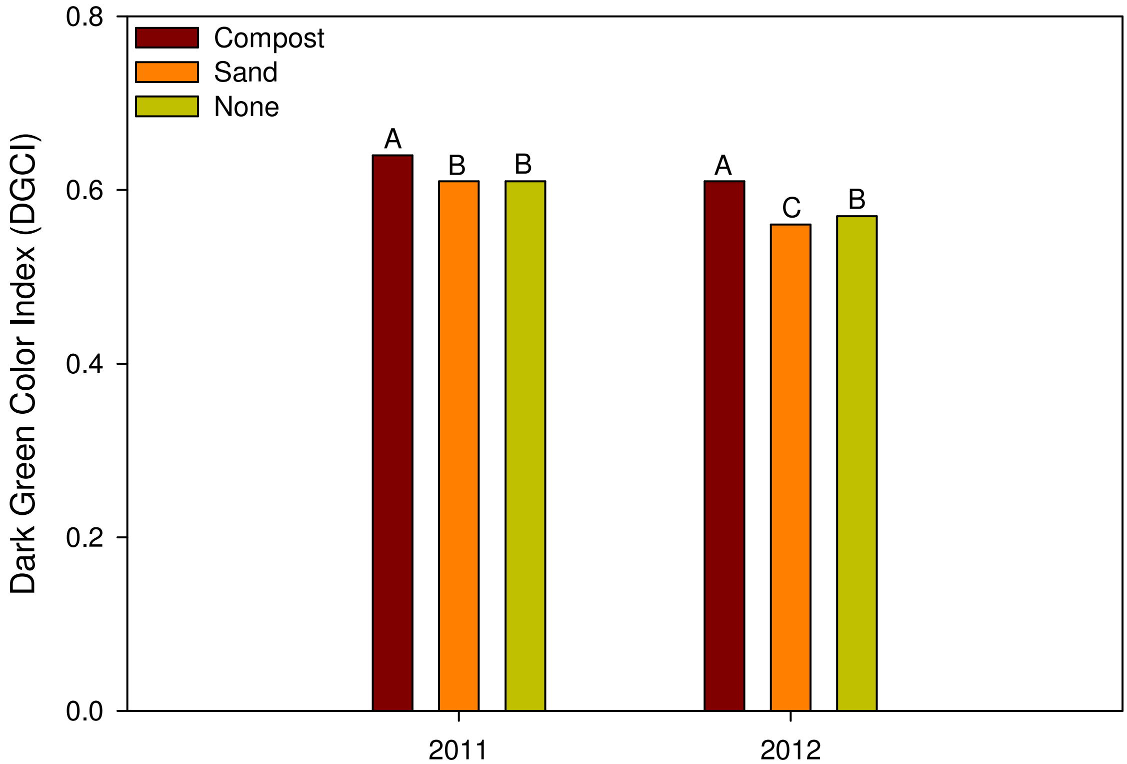

Fig. 2.3. The interaction effect of year and soil type on Dark Green Color Index (DGCI) when applied to two soils. 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

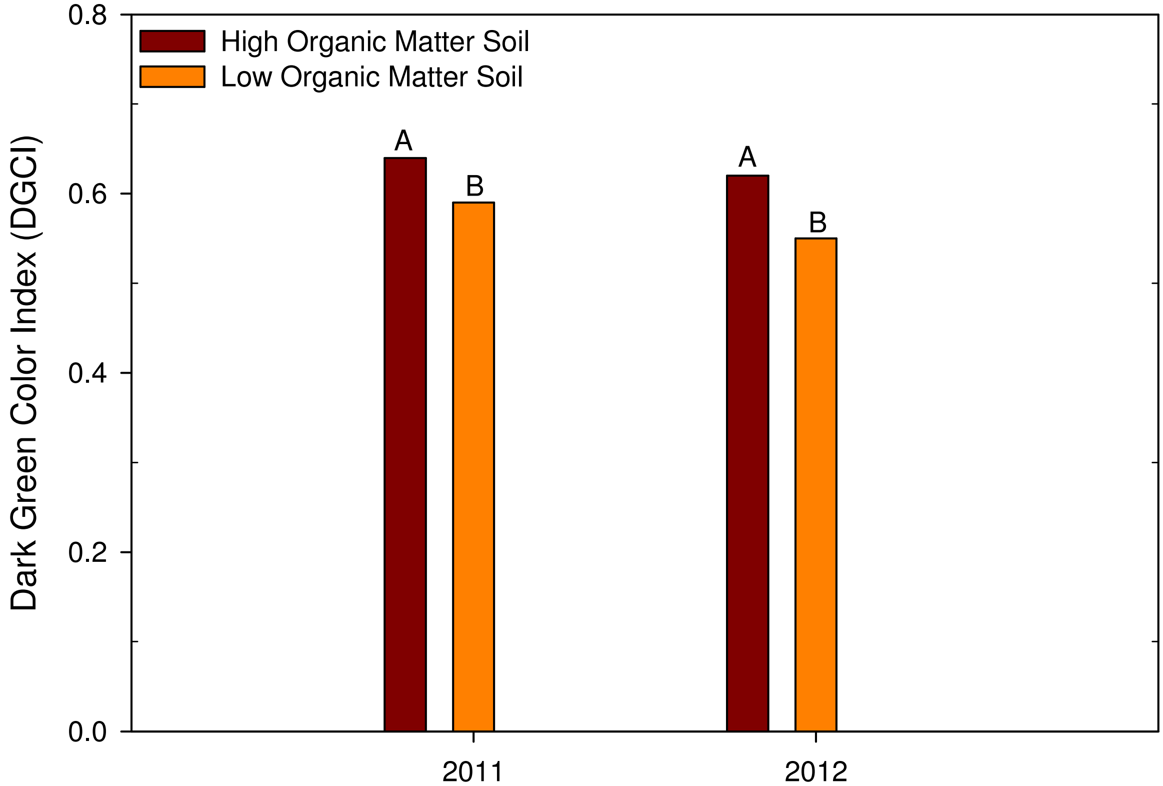

Fig. 2.4. The interaction effect of year and topdressing source on Dark Green Color Index (DGCI) when applied to two soils. 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

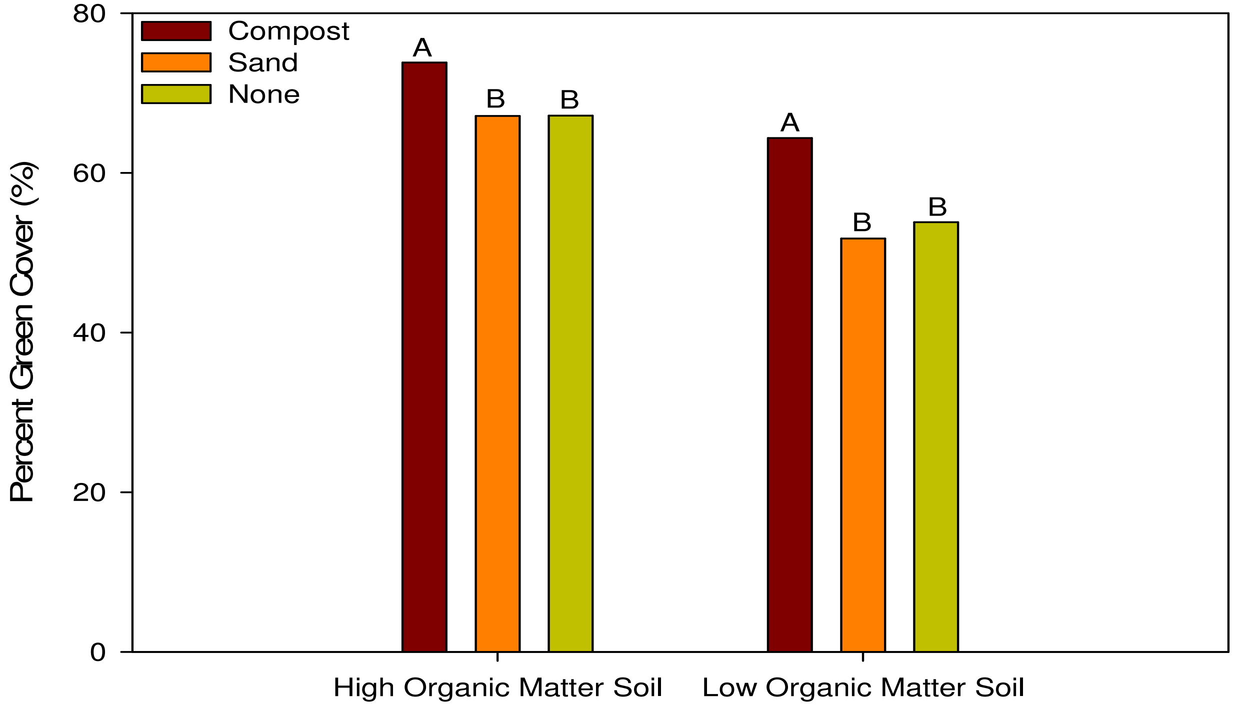

Fig. 2.5. The interaction effect of soil type and topdressing source on percent green cover, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

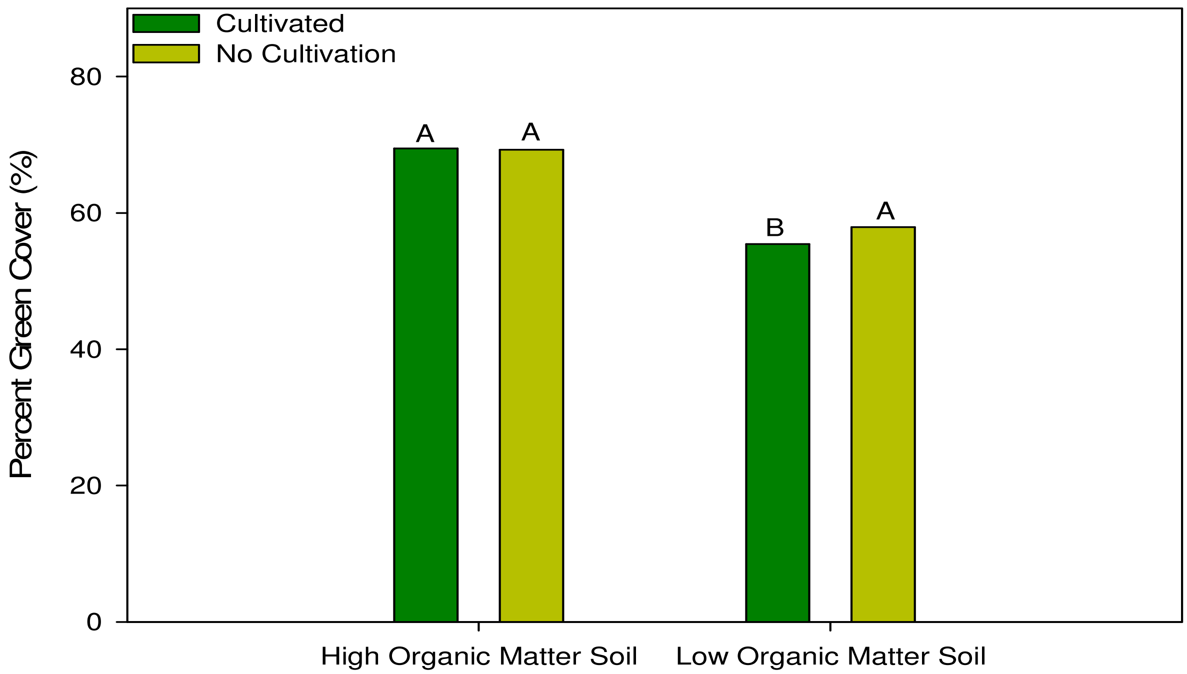

Fig. 2.6. The interaction effect of soil type and cultivation on percent cover, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

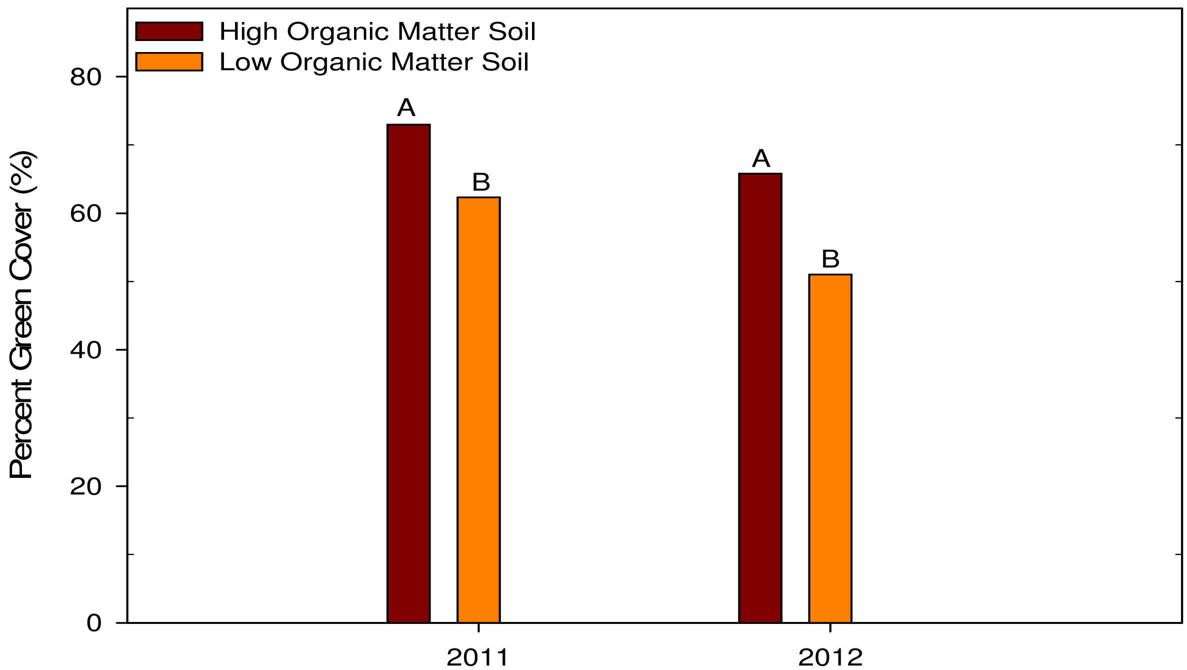

Fig. 2.7. The interaction effect of year and soil type on percent cover, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

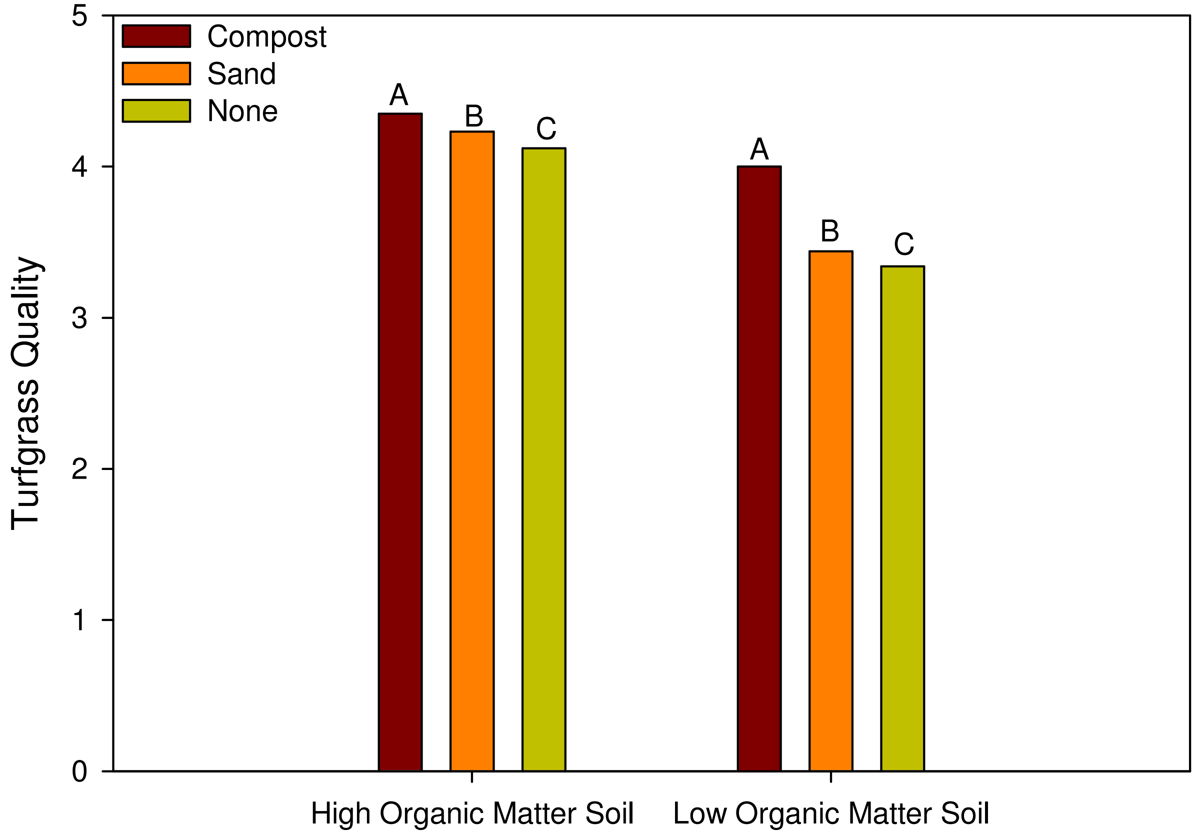

Fig. 2.8. The interaction effect of soil type and topdressing source on visual quality, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

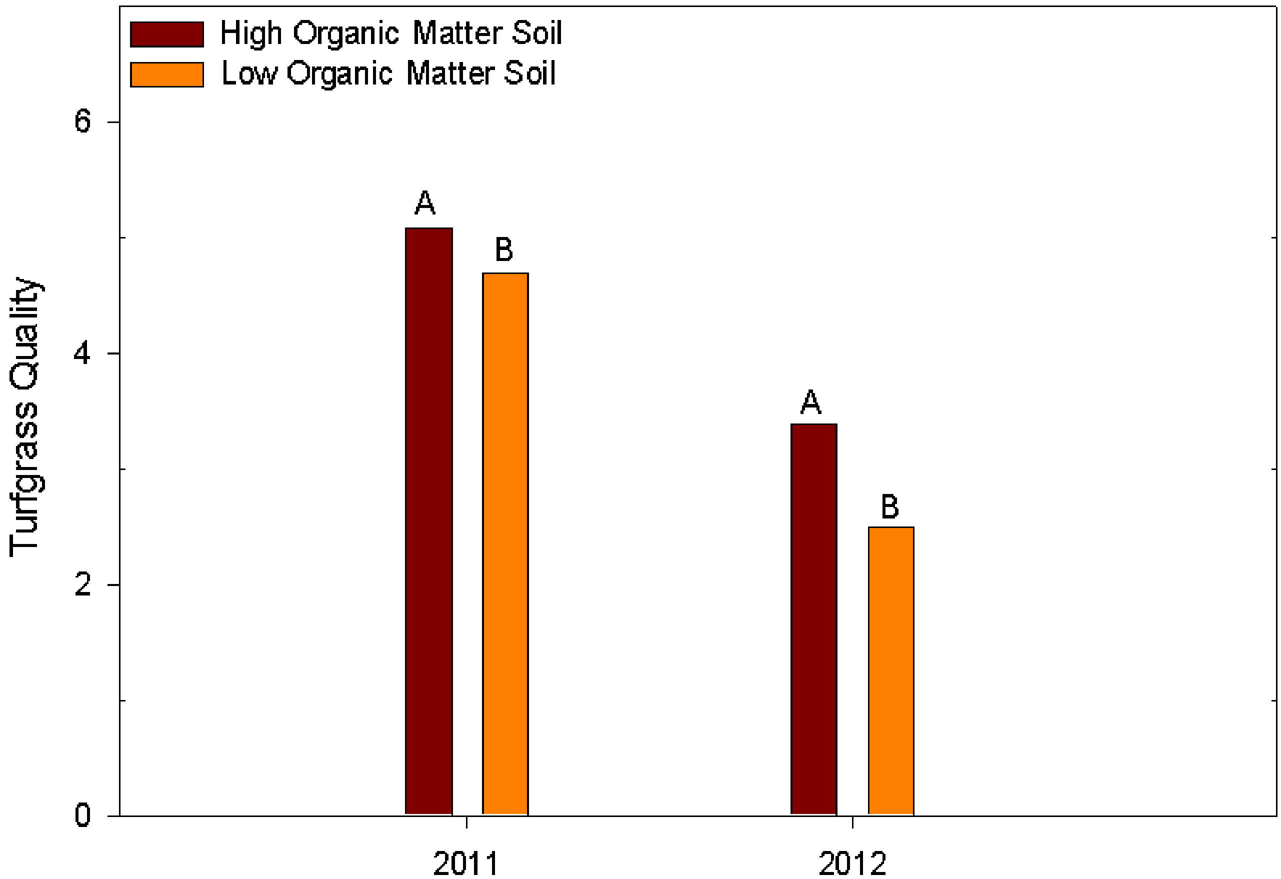

Fig. 2.9. The interaction effect of year and soil type on visual quality, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

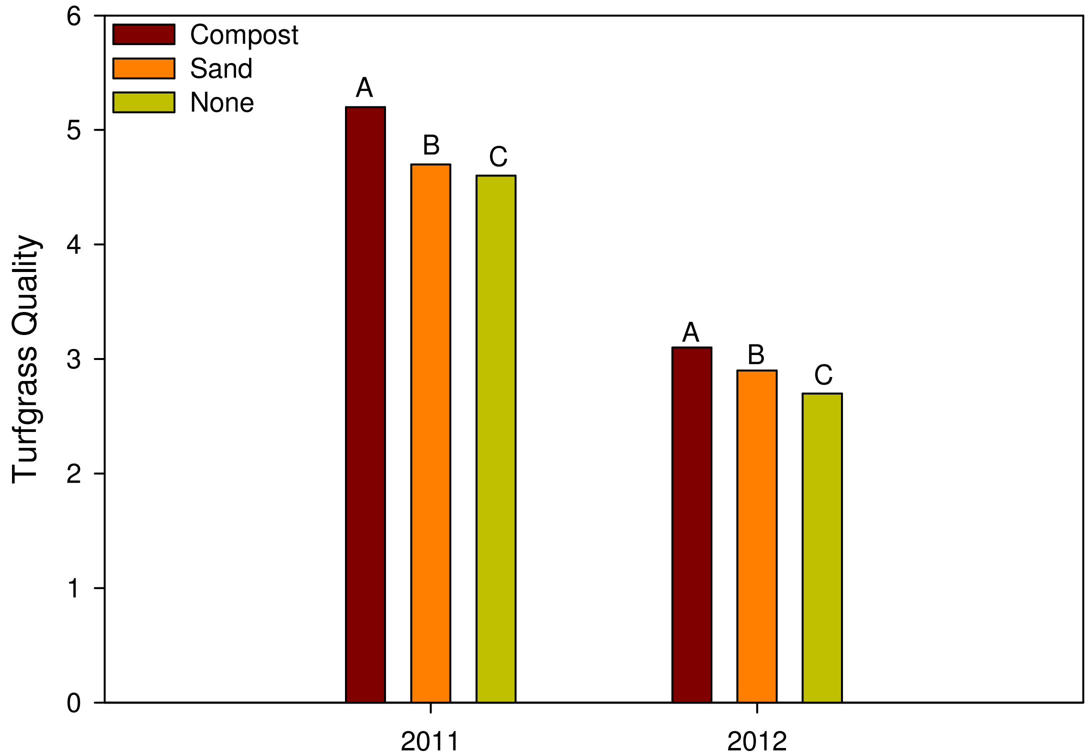

Fig. 2.10. The interaction effect of year and topdressing source on Visual Quality, 2011-2012. Treatments with the same letter within cultivation are not significantly different ($p < 0.05$) according to Fisher's LSD test.

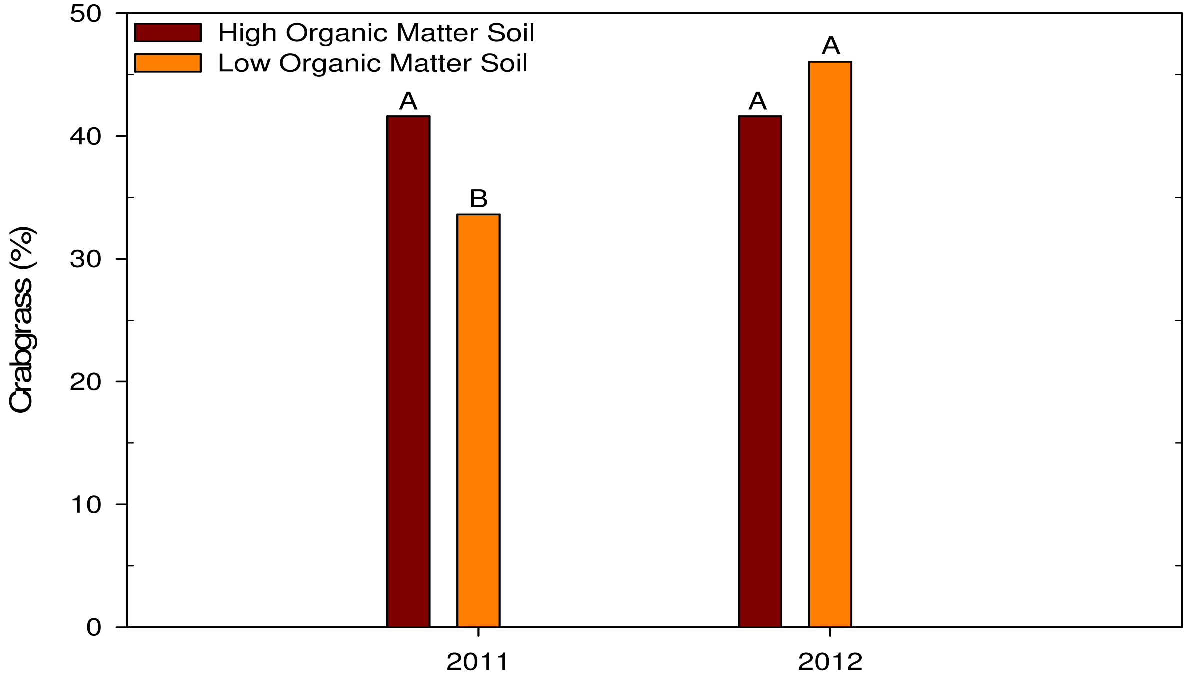

Fig. 2.11. The interaction effect of year and soil type on crabgrass percentage, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

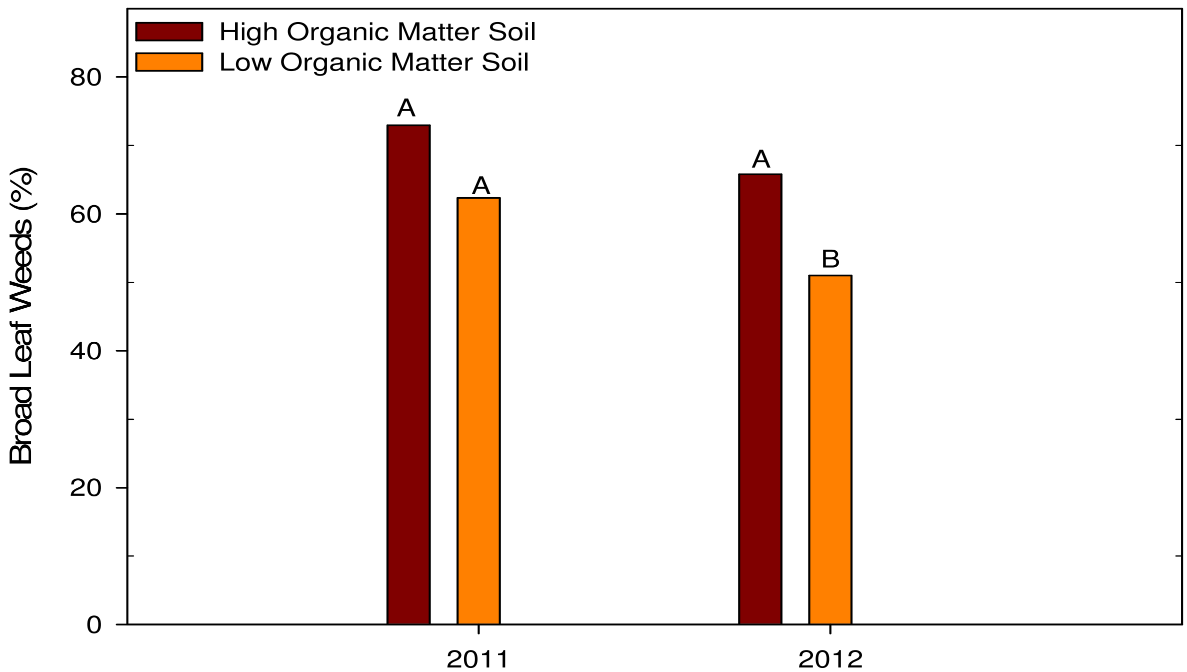

Fig. 2.12. The interaction effect of year and soil type on broadleaf weed percentage, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

Chapter 3

Leaf compost and sand topdressing effects on soil physical and chemical properties when applied to two soil types

Abstract

Currently, the research-based information regarding compost topdressing on athletic fields is very limited. The objectives of this research were to determine the effects of leaf compost and sand topdressing incorporated with core cultivation on soil physical and chemical properties when applied to low and high organic matter soils. The study was arranged in a 2 x 2 x 3 (soil type x core cultivation x topdressing) factorial where the main plots were set out in a latin rectangle design nested within two soil types with six replications. Soil type had two levels; high organic matter soil and low organic matter soil. Core cultivation had two levels; yes and no. Topdressing had three levels: 1) leaf compost topdressing applied at 0.635 cm in the spring and fall, 2) sand topdressing applied at 0.635 cm in the spring and fall, and 3) no topdressing applied. The main plots (topdressing) were split by core cultivation. Athletic field traffic was applied using a Cady Traffic Simulator during the fall to simulate a fall sports season. Compost treatments consistently showed greater differences on the low organic matter soil for lower surface hardness, higher volumetric soil moisture, lower total porosity, lower particle density, higher bulk density, and higher phosphorus levels. Differences were less dramatic on the higher organic matter soil, but the compost treatments had significantly higher volumetric soil moisture and organic matter content, along with significantly lower surface hardness values. Phosphorus content was significantly higher on plots receiving leaf compost topdressing on the low organic soil only.

Introduction

Recently, pressure to reduce pesticide use has increased interest in organic and/or synthetic pesticide-free management of golf courses, sports fields, and lawns. Composted materials are becoming a popular component of organic management programs used for home lawns and athletic fields in an effort to improve soil physical, chemical and biological properties. Composts are derived from a variety of materials including manures, yard wastes, and municipal biosolids. These materials have been used as a soil amendments by mixing on or off-site prior to turfgrass establishment or as topdressing to established turfgrass areas. Topdressing is the process of surface applying a material to established turfgrass most commonly done with sand to promote smooth playing surfaces and manage organic matter accumulation on golf course greens and tees, as well as on highly maintained athletic fields. Additionally, the use of compost topdressing as part of an integrated pest management (IPM) program is becoming more popular in an effort to reduce the use of fertilizer and pesticides.

Topdressing athletic fields with spent mushroom substrate (SMS) has been evaluated showing many positive impacts such as decreased bulk density, increased water retention, and decreased surface hardness (McNitt et al., 2004). Composts have also been used successfully to amend soils prior to construction to increase saturated hydraulic conductivity of compacted soils (Quinney and Hensley, 2004). Results from laboratory and greenhouse studies suggest that when incorporated into the soil at a rate of 22 mg ha^{-1} on dry weight basis, to a depth of 15 cm, composts can produce satisfactory plant growth, if adequate amounts of supplemental N fertilizers are applied (Sims, 1990). Increases in soil organic matter content have been documented with the application of compost made from biosolid and yard waste applied as topdressing to established turfgrass areas (Munoz et al., 2010)

The benefits of applying various composts as an amendment or topdressing have been shown in some previous research. However, concerns remain regarding excessive nutrient applications, particularly nitrogen and phosphorus, when composts are applied at a predetermined depth or volume and not according to nutrient concentration levels. In two studies conducted, research results indicate that incorporating composted sewage sludge into the soil raised soil phosphorus to an excessive level and increased sulfur concentrations (Provin et al., 2007). Topdressing poultry manure increased soil phosphorus levels when applied at 130 m^3 ha^{-1} to a 6 mm depth (Petrovic et al., 2008). Topdressing composted biosolids three times per year resulted in considerably higher soil phosphorus levels than defined as adequate relative to reported sufficiency levels for turfgrasses (Carrow et al., 2001; Munoz et al., 2010).

Few studies have evaluated different compost types applied as topdressing to playing surfaces. Additionally, repeated leaf compost applications have not been evaluated on multiple soil types subjected to simulated traffic. Leaf compost is considered desirable since it’s readily available and has a low phosphorus content. Furthermore, the effectiveness of core cultivation as an incorporation method for compost has not been thoroughly evaluated.

The objectives of this research were to determine the effects of leaf compost and sand topdressing incorporated with core cultivation on soil physical and chemical properties when applied to low and high organic matter soils.

Materials and Methods

This study was conducted at the University of Connecticut Plant Science Research and Education Facility located in Storrs, CT, during the 2010, 2011, and 2012 growing seasons. There were two soils used in the research area; a high organic matter soil classified as a

Woodbridge loam/sandy loam (Coarse-loamy, mixed, active, mesic Aquic Dystudepts), with a pH of 6.1, 52% sand, 34% silt, 14% clay, and 6% organic matter by weight. The other soil was a sandy loam subsoil with a pH of 5.3, 64% sand, 23% silt, 13% clay, and less than 1% organic matter by weight. The study was performed on a mixed stand of Kentucky bluegrass '25% Award, 25% America, 25% Alpine, and 25% Northstar'. The study was arranged in a 2 x 2 x 3 (soil type × core cultivation × topdressing) factorial set out in a split plot design. The main plots were set out in a latin rectangle design with six replications nested within two soil types. Soil type had two levels; high organic matter soil and low organic matter soil. Core cultivation had two levels; yes and no. Topdressing had three levels: 1) leaf compost topdressing applied at 0.635 cm in the spring and fall, 2) sand topdressing applied at 0.635 cm in the spring and fall (Table 3.1), and 3) no topdressing applied. The main plots (topdressing treatments), 3.0 m × 3.0 m, were split by cultivation into two subplots (yes and no), 1.5 m × 3.0 m, at the end of the 2010 growing season. The cultivated treatments were core cultivated in two directions using a Ryan GreensAire II (Steve Willand Inc., Brookfield, CT) equipped with1.58 cm hollow core tines following compost topdressing. Plots were mowed twice per week with a 53 cm walk behind rotary mower (The Toro Company, Bloomington, MN) at 5.0 cm and clippings were returned. Plots were irrigated as needed to prevent moisture stress.

Construction

The research area was constructed during the spring of 2010. The native sandy loam soil (A Horizon) was completely excavated to a 30.5 cm depth, screened to 2.5 cm × 3.6 cm, and compacted back into the high organic matter (6% w/w) study area. A low organic matter sandy loam (<1% w/w), screened to 1.9 cm, was trucked in and compacted into the low organic matter

study area. Plot areas were sodded with washed Kentucky bluegrass and core cultivated in two directions with 1.2 cm hollow core tines with 5 cm x 5 cm spacing to assist with sod establishment on May 11, 2010.

Topdressing Treatments and Fertility

During the first year of the study, topdressing treatments were applied on 16 June 2010 and 26 November 2010. Starter fertilizer (18-24-12, 9% ammoniacal nitrogen, 9% urea nitrogen, The Andersons, Maumee, Ohio) was applied on 25 May 2010 at a rate of 36.6 kg N ha^{-1}. Subsequent fertilizer applications derived from dried poultry waste, blood meal, feather meal and sulfate of potash (8-1-4) (North Country Organics, Bradford, VT) were applied at a rate of 49 kg N ha^{-1} from 22 June 2010 through 13 August 2010 every 21 days. Additional phosphorus applications were applied with a calcined bone meal product (0-16-0) (North Country Organics, Bradford, VT) at the rate of 22 kg P ha^{-1} per application on 13 August. Total nutrient applications from fertilizer sources for the growing season were as follows; 231.89 kg N ha^{-1}, 56 kg P ha^{-1}, and 101 kg K ha^{-1}. The nutrients applied from each leaf compost application were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

During the second year of the study, treatments were applied on 27 May 2011 and 2 December 2011. Pelletized dolomitic limestone was applied on 25 May at a rate of 2197 kg ha^{-1}. An initial application of corn gluten (9-0-0) (Harrington's Organic Land Care, Bloomfield CT) was applied at a rate of 98 kg N ha^{-1} on 10 May 2011. Subsequent fertilizer applications derived from dried poultry waste, blood meal, feather meal and sulfate of potash (8-2-4) (Macky's Home, Farm, Pet, and Wild Bird Supply, Willimantic, CT) were applied at a rate of 49 kg N ha^{-1} on 21 July 2011 and 25 August 2011. An additional phosphorus application was applied on 21

July 2011 using 0-16-0 (North Country Organics, Bradford, VT) at a rate of 22 kg P ha^{-1} Total nutrient applications from fertilizer sources for the growing season were as follows; 195 kg N ha^{-1},32 kg P ha^{-1}, and 41 kg K ha^{-1}. Total nutrient applications from leaf compost were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

During the third year of the study, treatments were applied on 31 May 2012 only. Pelletized dolomitic limestone was applied on 29 May at a rate of 2197 kg ha^{-1}. An initial application of fertilizer corn gluten Meal (9-0-0) (Macky's Home, Farm, Pet, and Wild Bird Supply, Willimantic, CT) was applied at a rate of 98 kg ha^{-1} on 15 May 2012. Subsequent fertilizer applications were applied from 6 July 2012 through 30 August 2012 using (8-2-4) (Macky's Home, Farm, Pet, and Wild Bird Supply) (Willimantic, CT) every 21 days at a rate of 24 kg N ha^{-1}. Additional phosphorus (0-16-0) (North Country Organics, Bradford, VT) was also applied on 13 August 2012 at a rate of 22 kg P ha^{-1}. Total nutrient applications from fertilizer sources for the growing season were as follows; 193 kg N ha^{-1}, 32 kg P ha^{-1}, and 41 kg K ha^{-1}. Total nutrient applications from leaf compost were as follows; 317 kg N ha^{-1}, 51 kg P ha^{-1}, and 130 kg K ha^{-1}.

Traffic Simulation

Traffic simulation was conducted using a Cady Traffic Simulator, a modified walk-behind core cultivation unit (Henderson et al., 2005). Each traffic event consisted of two forward passes over the entire study in different directions. The traffic in 2010 was conducted from 15 September to 29 November, totaling 25 traffic events. The traffic in 2011 went from 29 August to 18 November, totaling 27 traffic events. The traffic in 2012 went from 3 September to 21

November, totaling 28 traffic events. The target was three events per week, with weather and mechanical issues forcing occasional alterations in the schedule.

Data Collection

Surface hardness was measured using a 2.25 kg Clegg Impact Tester (Clegg, 1976). Clegg measurements were an average of six single drops of the missile within each plot (ASTM, 2008). Data were taken once per month from May through November. Volumetric soil moisture measurements were taken once per month from May through November, and were an average of six readings per plot taken with a Field Scout TDR 300 Soil Moisture Meter (Spectrum Technologies, Inc.) equipped with two 3.8 cm measuring rods. Rotational traction was measured using a Canaway traction device (Canaway and Bell, 1986). Data were collected once a month from May to November, with three subsamples collected and averaged on each date.

Two 4.9 cm diameter undisturbed soil cores were randomly extracted to a depth of 7.62 cm from each treatment following the traffic period using an AMS soil core sampling device (Model 404.67, AMS, Inc.). Sampling was conducted immediately following the end of the traffic period in 2011 and 2012. Saturated hydraulic conductivity was measure in the laboratory using a permeameter to maintain a constant head of water during the entire duration of the test (ASTM, 2006a). Bulk density was calculated using the oven dry mass of the soil and the volume of the cores (ASTM, 2006a). Samples from each core were sent to an independent lab (Hummel and Co., Inc.) to measure particle density (ASTM, 2006b). Aeration porosity was determined by subtracting the capillary porosity, measured gravimetrically after 72 h using a porous plate and pressure chamber at -33.3 kPa (ASTM, 2002a.), from the total porosity, calculated from the bulk and particle densities (ASTM, 2006a, 2006b). Organic matter contents were measured using the

loss on ignition method (ASTM, 2002b). Extractable phosphorus was measured at a depth of 0 – 7.62 cm below the topdressing interface using the Modified Morgan (sodium acetate buffered at pH 4.8) extractant.

Statistical Analysis

Analysis of variance was used to test for significant ($p \leq 0.05$) differences between treatments using the MIXED and GLM procedures of the SAS statistical software v. 9.3 (SAS Institute Inc., Cary, NC). The 2010 growing season was analyzed separately from the other years because the core cultivation treatments had not been imposed during the establishment year in 2010. Beginning in 2011 and continuing through 2012, core cultivation or no cultivation was included as subplot treatments. Data from the 2011 and 2012 growing seasons were combined, since topdressing and cultivation typically have cumulative effects and there was an interest to see if any cumulative effects were present from these treatments. When data were combined for 2011 and 2012, years were treated as a repeated measure since topdressing and cultivation was done on a yearly basis. Where differences between treatments using appropriate F-tests showed significance, mean separations were conducted using Fisher's LSD test with a 0.05 probability level.

Results

Soil Physical and Chemical Properties

Aeration Porosity

Differences in aeration porosity were only observed as a year main effect showing the 2012 growing season had significantly higher aeration porosity values than the 2011 growing season (Table 3.4).

Capillary Porosity

Differences in capillary porosity were primarily observed as soil, treatment, and year main effects (Table 3.4). The high organic matter soil had significantly higher capillary porosity values than the low organic matter soil, and the 2011 growing season had significantly higher capillary porosity values than the 2012 growing season. Plots receiving leaf compost topdressing had significantly higher capillary porosity values than the untreated control and sand topdressed plots. This could be caused due to the cumulative effect of traffic. Year × soil and year × treatment interactions were also observed during the 2011-2012 growing seasons. The year × soil interaction shows the high organic matter soil having significantly higher capillary porosity values than the low organic matter soil regardless of year (Fig. 3.1). The interaction is shown by greater differences between soil types during the 2011 growing season compared to the 2012 growing season. The year × treatment interaction shows plots that received leaf compost topdressing had significantly higher capillary porosity values than all other treatments during the 2012 growing season only (Fig. 3.2).

Bulk Density

Bulk density differences were generally observed as soil, treatment, and year main effects along with soil × treat, year × treat, and year × soil interactions (Table 3.3). The high organic matter soil had significantly lower bulk density values than the high organic matter soil during the 2011-2012 growing seasons. The treatment main effect shows plots receiving leaf compost topdressing had significantly lower bulk density values than the untreated control and sand topdressed plots, while the year main effect shows significantly lower bulk density values during the 2012 growing season compared to the 2011 growing season.

The soil × treatment interaction shows that plots receiving leaf compost topdressing having significantly lower bulk density values than the untreated control regardless of soil type (Fig. 3.3). The interaction is shown by having no differences between the sand topdressed plots and the untreated control in the high organic matter soil, but having differences between the sand topdressed plots and untreated control plots in the low organic matter soil. The year × treatment interaction shows sand topdressed plots had the lowest bulk density values during the 2011 growing season, however in 2012, the plots that received leaf compost topdressing had significantly lower bulk density values compared to all other treatments (Fig. 3.4). The year × soil interaction shows the high organic matter soil had significantly lower bulk density values compared to the low organic matter soil regardless of year (Fig. 3.5). There were greater differences between soil types in the 2011 growing season compared to the 2012 growing season.

Saturated Hydraulic Conductivity

Differences in saturated hydraulic conductivity (KSAT) were observed only as a treatment main effect (Table 3.4.) Plots receiving sand topdressing had significantly higher KSAT values than all other treatments.

Volumetric Soil Moisture

Differences in volumetric soil moisture were observed as an overall soil main effect during the 2010 growing season (Table 3.6). The high organic matter soil retained significantly higher soil moisture compared to the low organic matter soil. On 9 November, there was also a

treatment main effect where leaf compost treated plots had significantly higher soil moisture compared to all other treatments.

During the 2011-2012 growing seasons, soil, year, and treatment main effect were observed (Table 3.4). The high organic matter soil retained significantly higher volumetric soil moisture than the low organic matter soil, while 2012 had significantly higher moisture content than the 2011 growing season. The treatment main effect showed plots receiving leaf compost topdressing retained significantly higher volumetric soil moisture compared to plots receiving sand topdressing and the untreated control. A soil × treatment interaction was observed where leaf compost treated plots retained greater moisture than all other treatments regardless of soil type (Fig. 3.6). Greater differences between the sand topdressed plots and the untreated control on the high organic matter soil compared to the low organic matter soil show the interaction effect. A soil × cultivation interaction was also observed where cultivated plots retained significantly more moisture than plots that did not receive cultivation in the high organic matter soil only (Fig. 3.7).

Year × soil and year × treatment interactions were also observed during the 2011-2012 growing seasons. The high organic matter soil retained significantly more water than the low organic matter soil regardless of year (Fig. 3.8). Greater differences between soil type in 2011 compared to 2012 show the interaction effect. Plots that received leaf compost topdressing had significantly higher moisture contents than all other treatments regardless of year (Fig. 3.9). The interaction shows greater differences between treatments in 2012 compared to 2011.

Organic Matter

Organic matter differences were observed as soil, treatment, and year main effects along with soil × treat and year × treat interactions (Table 3.4). The soil main effect showed the high organic matter soil having significantly higher organic matter content than the low organic matter soil. Plots receiving leaf compost topdressing had significantly higher organic matter content than plots receiving sand topdressing or the untreated control, while the 2012 growing season had significantly higher organic matter than the 2011 growing season. The soil × treatment interaction shows that plots receiving leaf compost topdressing had significantly higher organic matter content than all other treatments regardless of soil type (Fig. 3.10). The interaction effect shows differences between the sand topdressed plots and untreated control in the high organic matter soil only. Compost topdressed plots also showed significantly higher organic matter content compared to all other treatments regardless of year (Fig. 3.11). Greater differences were shown between soil type during the 2012 growing season compared to the 2011 growing season.

Particle Density

Differences in particle density were observed only as a soil main effect (Table 3.4). The low organic matter soil had higher particle density values than the high organic matter soil.

Soil Phosphorus Concentrations

Phosphorus differences were observed as soil, treatment, and year main effects along with soil × treatment, year × treatment, year × soil, and year × soil × treatment interactions (Table 3.4). Overall, the low organic matter soil had significantly higher phosphorus

concentrations than the high organic matter soil. Plots receiving leaf compost topdressing had significantly higher phosphorus concentrations than all other treatments and the 2012 growing season had significantly higher phosphorus concentrations than the 2011 growing season. The soil × treatment interaction shows plots receiving leaf compost topdressing had significantly higher phosphorus concentrations compared to all other treatments regardless of soil type (Fig. 3.12). Greater differences between treatments in the low organic matter soil compared to the high organic matter soil were noticed – especially for compost treated plots. An overall increase in phosphorus was noticed from the 2011 to the 2012 growing season as the year × treatment interaction shows plots receiving leaf compost topdressing had significantly higher phosphorus concentrations than all other treatments in 2012 only (Fig. 3.13). Data from the year × soil interaction shows the low organic matter soil had significantly higher phosphorus levels than the high organic matter soil regardless of year (Fig. 3.14). Differences between soil type during the 2012 growing season compared to the 2011 growing season show the interaction effect. The year × soil × treatment interaction shows a significant increase in phosphorus levels in each soil from the 2011 growing season to the 2012 growing season (Fig. 3.15). During the 2011 growing season, plots receiving leaf compost topdressing had significantly higher phosphorus levels than all other treatments in the low organic matter soil only. However, during the 2012 growing season, plots receiving leaf compost topdressing had significantly higher phosphorus levels than all other treatments in both soils.

Playing Surface Characteristics

Surface Hardness

There were no significant differences between treatments during September 2010 (Table 3.3). During November 2010, the high organic matter soil had significantly lower surface

hardness values than the low organic matter soil. Plots that received leaf compost topdressing had significantly lower surface hardness values than the untreated control, but were not different from plots that received sand topdressing.

During the 2011 and 2012 growing seasons, soil, treatment, and year main effects were significant as well as a year × soil interaction (Table 3.5). The high organic matter soil had significantly lower surface hardness values while plots that received leaf compost topdressing had significantly lower surface hardness values compared to all other treatments. The 2012 growing season had significantly lower surface hardness values than the 2011 growing season. The year × soil interaction shows the high organic matter soil had significantly lower surface hardness values compared to the low organic matter soil regardless of year (Fig. 3.16). The interaction effect is shown as greater differences between soil types during the 2011 growing season compared to the 2012 growing season.

Rotational Traction

Traction readings were not taken during the 2010. During the 2011-2012 growing seasons, there were soil, treatment, and year main effects (Table 3.5). The low organic matter soil and 2011 growing season had significantly higher rotational traction values than the high organic matter soil and the 2012 growing season. Plots that received leaf compost topdressing had significantly higher rotational traction values that the sand topdressed plots, but were not different than the untreated control.

Soil × treatment, year × treatment, and year × soil interactions were observed during the 2011-2012 growing seasons. The soil × treatment interaction showed the untreated control having significantly lower rotational traction values than the plots receiving leaf compost and sand topdressing in the high organic matter soil (Fig. 3.17). However, the untreated control had

significantly higher rotational traction values than all other treatments on the low organic matter soil. The year × treatment interaction, the plots receiving sand topdressing had significantly lower rotational traction values than the untreated control and plots receiving leaf compost topdressing during the 2011 growing season only (Fig. 3.18). The year × soil interaction shows the high organic matter soil having significantly lower traction values than the low organic matter soil regardless of year (Fig. 3.19). The interaction effect is shown as a greater difference between the two soil types in the 2012 growing season compared to the 2011 growing season. All rotational traction values were well above the acceptable minimum of 10 N m (Bell and Holmes, 1988).

Discussion

Leaf compost topdressing applications significantly reduced surface hardness, increased volumetric soil moisture, and considerably altered soil physical and chemical properties. As leaf compost topdressing applications increased soil physical properties and playing surface characteristics generally improved such as reduced bulk density values, higher soil moisture retention and lower surface hardness values. These results are consistent with previous research where lower bulk density values, higher soil moisture retention, and lower surface hardness values were obtained from topdressing athletic fields with spent mushroom substrate (SMS) (McNitt et al., 2004). Additionally, capillary porosity, total porosity, and organic matter content significantly increased as leaf compost topdressing applications increased regardless of soil type.

Plots receiving leaf compost topdressing on the low organic matter soil had significantly more phosphorus compared to all other treatments. The amount of phosphorus retained increased from 2.8 kg P ha^{-1} in 2011 to 11.8 kg P ha^{-1}in 2012, which is above the agronomic critical

concentration level for turfgrass. Similar spikes in phosphorus levels have been documented in other research (Provin et al., 2007; Petrovic et al., 2008; Munoz et al., 2010).

Data from the year × soil interaction shows greater differences between soil type during the 2012 growing season compared to the 2011 growing season. These results are noteworthy considering the same amount of phosphorus was applied to both soil types over the duration of the study. The difference in phosphorus between the two soil types is likely attributed to phosphorus fixation. The quantity of soluble Fe and Al in a particular soil can greatly affect the potential for phosphorus fixation, particularly under acid conditions. Soluble forms of phosphorus that may be released will quickly react to form less soluble Fe and Al phosphates. The Fe and Al contents were drastically different between the two soils. For example, the average Fe and Al contents of the low organic matter soil were 13.5 ppm and 124.4 ppm respectively with an average pH of 5.9, when averaged across all the plots. In contrast, the average Fe and Al contents of the high organic matter soil were 19.8 ppm and 206.4 ppm respectively with a pH of 5.6, when averaged across all the plots. Therefore, the high organic matter had much greater potential to form the less soluble Fe and Al phosphates, which were likely not dissolved by the modified Morgan extractant solution. Even though these forms of phosphorus are less soluble than other more plant available forms, the phosphorus is still present in the soil and would be susceptible to movement off-site by direct runoff and/or soil erosion.

Conclusions

Although there are many benefits to applying compost topdressing, the changes in the chemical properties data clearly indicate that phosphorus is a limiting factor in how much compost can be applied. A more sustainable approach to utilizing compost topdressing on

athletic fields may entail reducing the rate of application and reducing the frequency of application to allow annual core cultivation treatments to help incorporate the compost into the existing soil. Phosphorus levels must be routinely monitored following each compost application to ensure that excessive phosphorus is not applied.

Table 3.1. Chemical characteristics, physical characteristics and maturity level of leaf compost topdressing material.

	Chemical Characteristics						Physical Characteristics		Maturity
Parameter	pH	Soluble Salts (mmhos cm^{-1})	N (%)	P (%)	K (%)	C:N Ratio	Organic matter (g kg^{-1})	Moisture Content (%)	Respirometry (mg CO_2-C/g*)
Leaf Compost	7.3	0.92	0.88	0.14	0.37	15.4	263	46.4	1.4 †

* mg CO_2-C/g organic matter/day – Respirometry(CO_2 evolution) provides a measurement of the relative microbial activity in a compost. Therefore, this can be used as an estimate of compost stability.

† Interpretive index from the U.S. Compost Council Test Methods, <2 = Very Stable – Well cured compost, no continued decomposition, no odors, 2-8 = Stable – cured compost, odor production not likely, minimal impact on soil carbon and nitrogen dynamics

Table 3.2. Characteristics of sand topdressing compared to USGA recommendations.

	Soil Separate %				% Retained					
Treatment	**Sand**	**Silt**	**Clay**	**No. 10 Gravel 2 mm**	**No. 18 VCS 1 mm**	**No. 35 CS 0.5 mm**	**No. 60 MS 0.25 mm**	**No. 100 FS 0.15 mm**	**No. 140 VFS 0.10 mm**	**No. 270 VFS 0.05 mm**
Coarse Sand (AA Will Mat. 2mm)	99.5	0.0	0.4	0.1	11.0	31.5	42.0	13.0	1.6	0.4
USGA Rec. for Putting Green Const		**$\leq$ 5%**	**$\leq$ 3%**	**$\leq$ 3% Gravel $\leq$ 10% Combined**		**$\geq$ 60%**		**$\leq$ 20%**	**$\leq$ 5%**	

Table 3.3. Effect of soil type and topdressing source on surface hardness values† 2010.

Main effects	30 Sept	9 Nov
Soil	—— gMAX ——	
High	51.45 a‡	58.89 b
Low	50.48 a	72.67 a
Treatment (Treat)		
None	52.25 a	68.66 a
Sand	50.46 a	66.65 ab
Compost	50.20 a	62.03 b
Variation source	ANOVA	
Soil	NS¶	*
Treat	NS	**
Soil × Treat	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
† Surface Hardness values were taken with a 2.25 kg Clegg Impact Tester.
‡Means in a column followed by the same letter are not significantly different.
¶NS, not significant.

Table 3.4. Effect of soil type, cultivation, year, and topdressing source on soil physical properties, soil chemical properties and playing surface characteristics averaged across dates, 2011-2012.

Main effects	Aeration Porosity	Capillar y Porosity	Bulk Density	Hydraulic Conductivity	VMC†	Organic Matter	Particle Density	Extractable Phosphorus††
Soil	%	%	g cm^{-3}	cm h^{-1}	%	g kg^{-1}	g cm^{-3}	kg P ha^{-1}
High	7.18	42.22 a	1.31 b	0.47 a	32.70	76.8 a	2.59 b	1.76 b
Low	7.17 a	27.88 b	1.74 a	0.61 a	22.21	23.8 b	2.68 a	4.37 a
Cultivation (Cult)								
Yes	6.90 a	35.20 a	6.90 a	0.40 a	27.49	49.9 a	2.64 a	3.21 a
No	7.45 a	34.90 a	7.45 a	0.60 a	27.49	50.7 a	2.64 a	2.91 a
Year								
2011	2.13 b	41.43 a	1.60 a	0.51 a	25.52	42.1 b	2.63 a	1.26 b
2012	16.49 a	28.67 b	1.44 b	0.57 a	29.40	58.6 a	2.64 a	4.88 a
Treatment (Treat)								
None	6.40 a	34.09 b	1.57 a	0.40 b	27.39	46.3 b	2.64 a	2.52 b
Sand	9.13 a	33.08 b	1.52 b	0.88 a	22.67	42.2 c	2.63 a	2.31 b
Compost	6.00 a	37.98 a	1.47 c	0.35 b	32.31	62.4 a	2.63 a	4.38 a
Variation source				ANOVA				
Treat	NS¶	*	***	*	***	***	NS	***
Soil	NS	**	***	NS	**	***	***	***
Soil × Treat	NS	NS	**	NS	*	*	NS	***
Cult	NS	NS	NS	NS	NS	NS	NS	NS
Treat × Cult	NS	NS	NS	NS	NS	NS	NS	NS
Soil × Cult	NS	NS	NS	NS	*	NS	NS	NS
Soil × Treat × Cult	NS	NS	NS	NS	NS	NS	NS	NS
Year	***	***	***	NS	***	***	NS	***
Year × Treat	NS	***	***	NS	***	***	NS	***
Year × Soil	NS	**	***	NS	***	NS	NS	**
Year × Soil × Treat	NS	NS	NS	NS	NS	NS	NS	**
Year × Cult	NS	NS	NS	NS	NS	NS	NS	NS
Year × Treat × Cult	NS	NS	NS	NS	NS	NS	NS	NS
Year × Soil × Cult	NS	NS	NS	NS	NS	NS	NS	NS
Year × Soil × Treat × Cult	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
‡Means in a column followed by the same letter are not significantly different.
¶NS, not significant.
†Volumetric moisture content was measured with a Field Scout TDR 300 moisture meter.
††Phosphorus values were measured after the 2011 and 2012 growing seasons and assessed using the Modified Morgan soil test.

Table 3.5. Effect of compost and sand topdressing playing surface characteristics averaged across dates, 2011-2012.

Main effects	Surface Hardness†	Rotational Traction††
Soil	gMAX	N m
High	50.80 b‡	43.63 b
Low	80.58 a	46.12 a
Cultivation (Cult)		
Yes	64.29 a	44.88 a
No	67.09 a	44.87 a
Year		
2011	78.13 a	47.20 a
2012	53.25 b	42.55 b
Treatment (Treat)		
None	71.50 a	45.36 a
Sand	67.96 a	44.13 b
Compost	57.62 b	45.14 a
Variation source	ANOVA	
Treat	***	*
Soil	**	***
Soil × Treat	NS¶	***
Cult	NS	NS
Treat × Cult	NS	NS
Soil × Cult	NS	NS
Soil × Treat × Cult	NS	NS
Year	***	***
Year × Treat	NS	*
Year × Soil	***	*
Year × Soil × Treat	NS	NS
Year × Cult	NS	NS
Year × Treat × Cult	NS	NS
Year × Soil × Cult	NS	NS
Year × Soil × Treat × Cult	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
‡Means in a column followed by the same letter are not significantly different.
¶NS, not significant.
†Surface hardness was measured using a 2.25 kg Clegg impact hammer.
††Rotational Traction was measured with a Canaway traction device.

Table 3.6. Effect of soil type and topdressing source on volumetric soil moisture† 2010.

Main effects	30 Sept	9 Nov
Soil	———%———	
High	32.78 a‡	30.51 a
Low	24.84 b	19.27 b
Treatment (Treat)		
None	28.80 a	24.30 b
Sand	28.36 a	24.45 b
Compost	29.28 a	25.93 a
Variation source	ANOVA	
Soil	***	***
Treat	NS¶	*
Soil × Treat	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Volumetric soil moisture was measured with a Field Scout TDR 300 moisture meter.
‡Means in a column followed by the same letter are not significantly different.
¶NS, not significant.

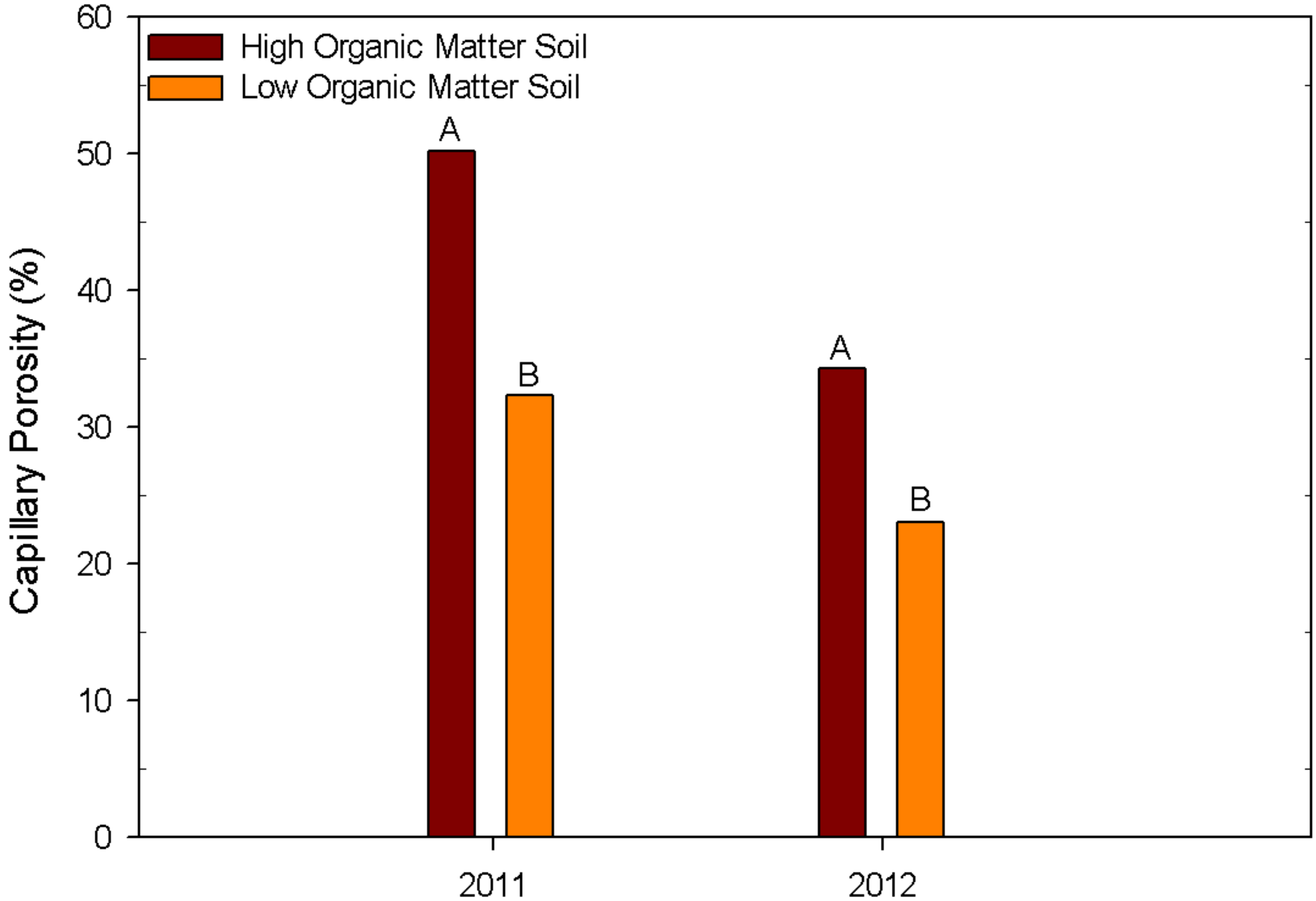

Fig. 3.1. The interaction effect of year and soil on capillary porosity values 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

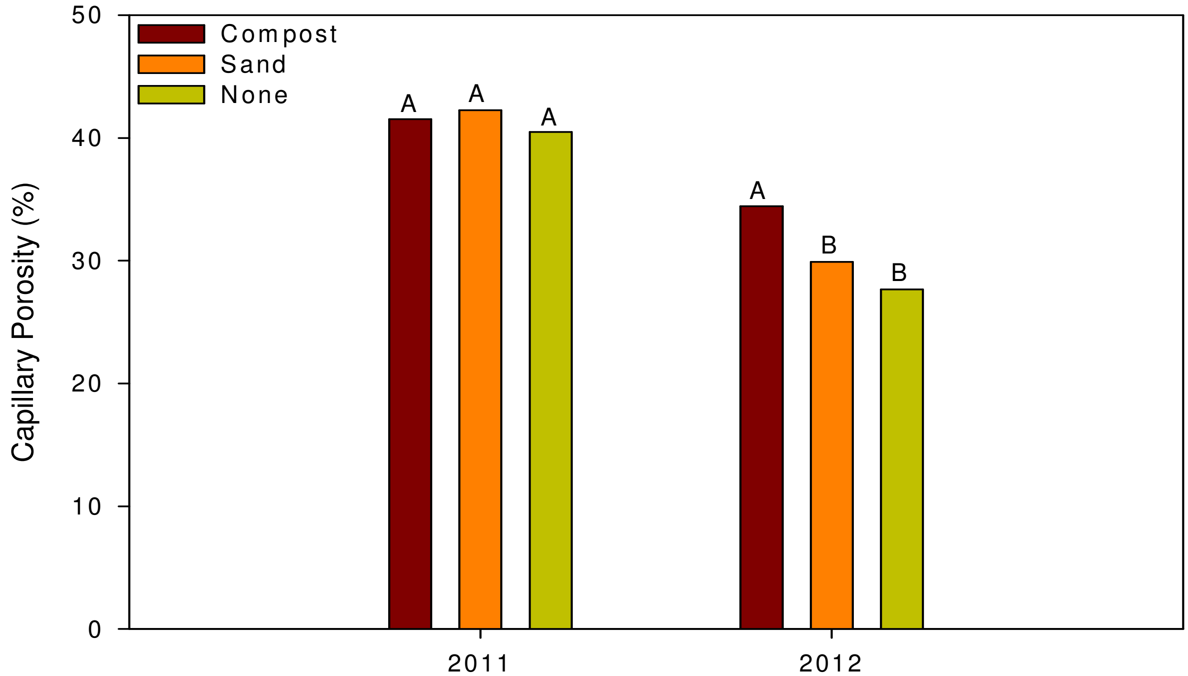

Fig. 3.2. The interaction effect of year and topdressing source on capillary porosity values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

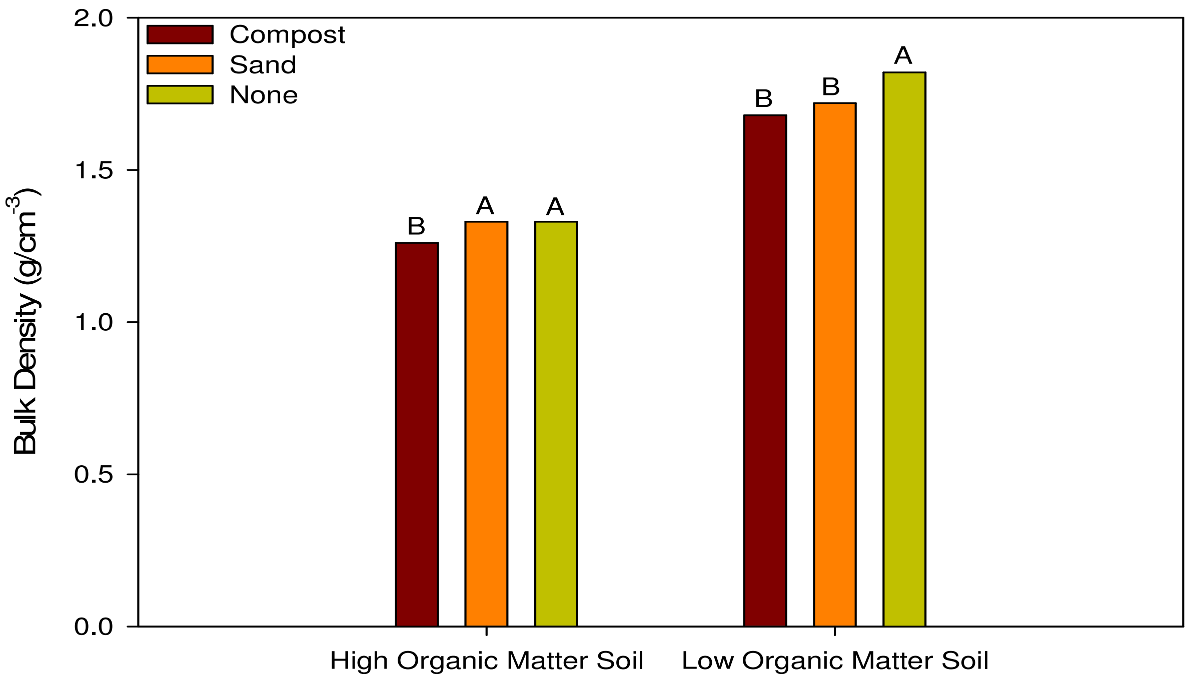

Fig. 3.3. The interaction effect of soil type and topdressing source on bulk density values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

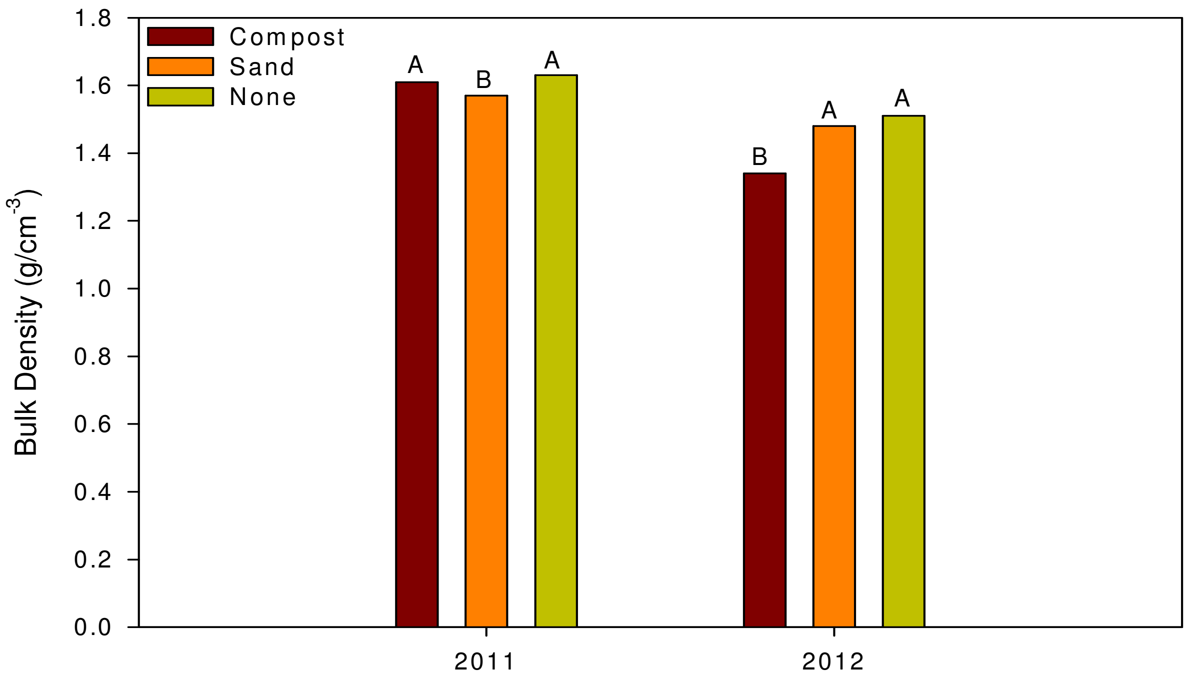

Fig. 3.4. The interaction effect of year and topdressing source on bulk density values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

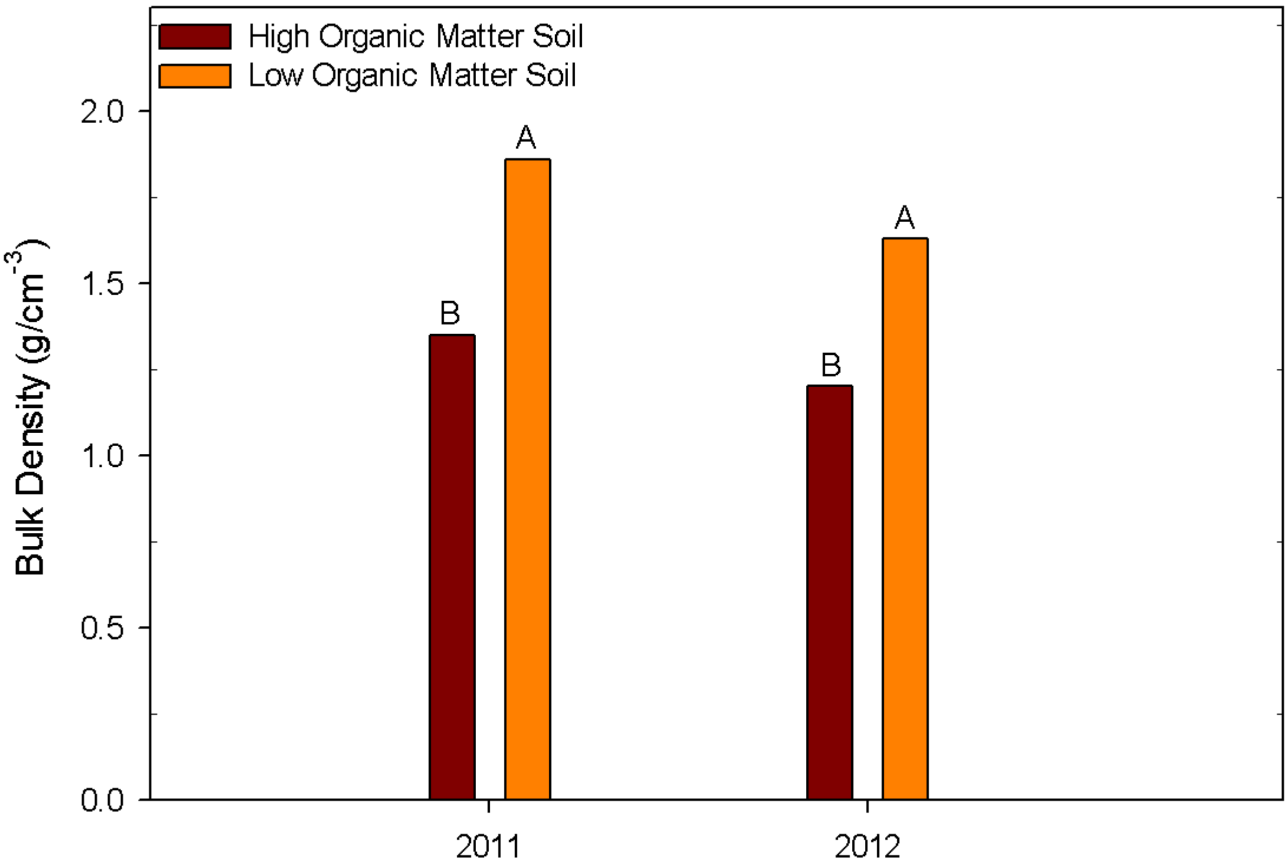

Fig. 3.5. The interaction effect of year and soil type on bulk density values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

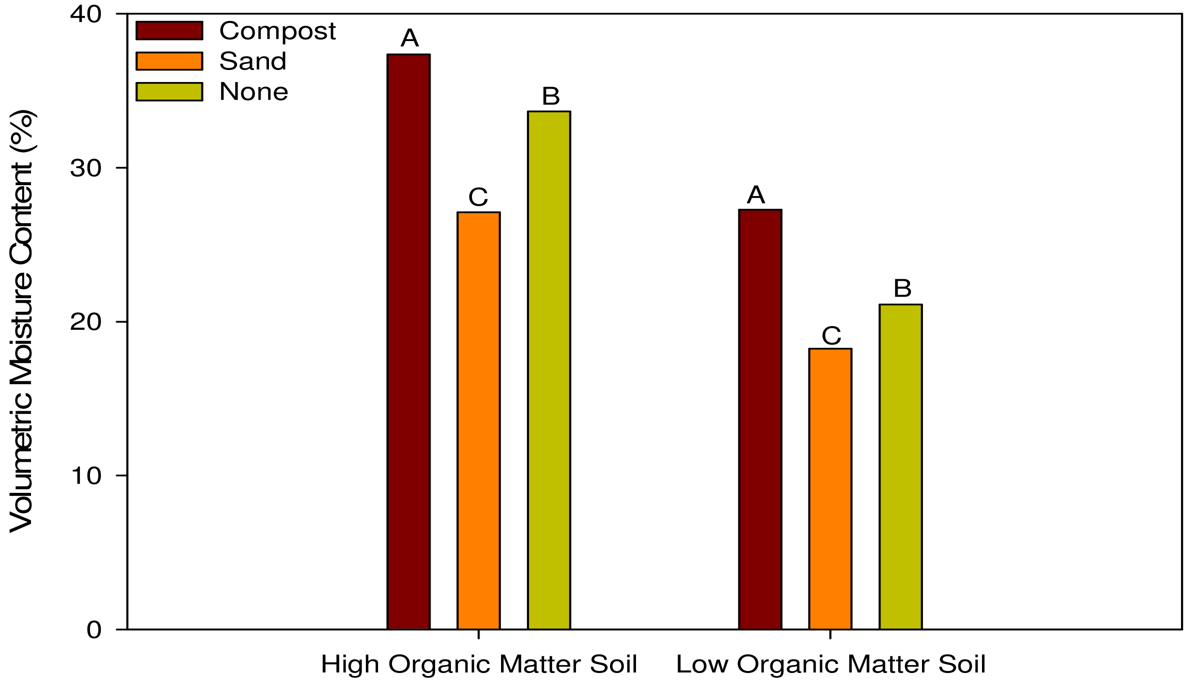

Fig. 3.6. The interaction effect of soil type and topdressing source on volumetric moisture content (VMC) values, 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

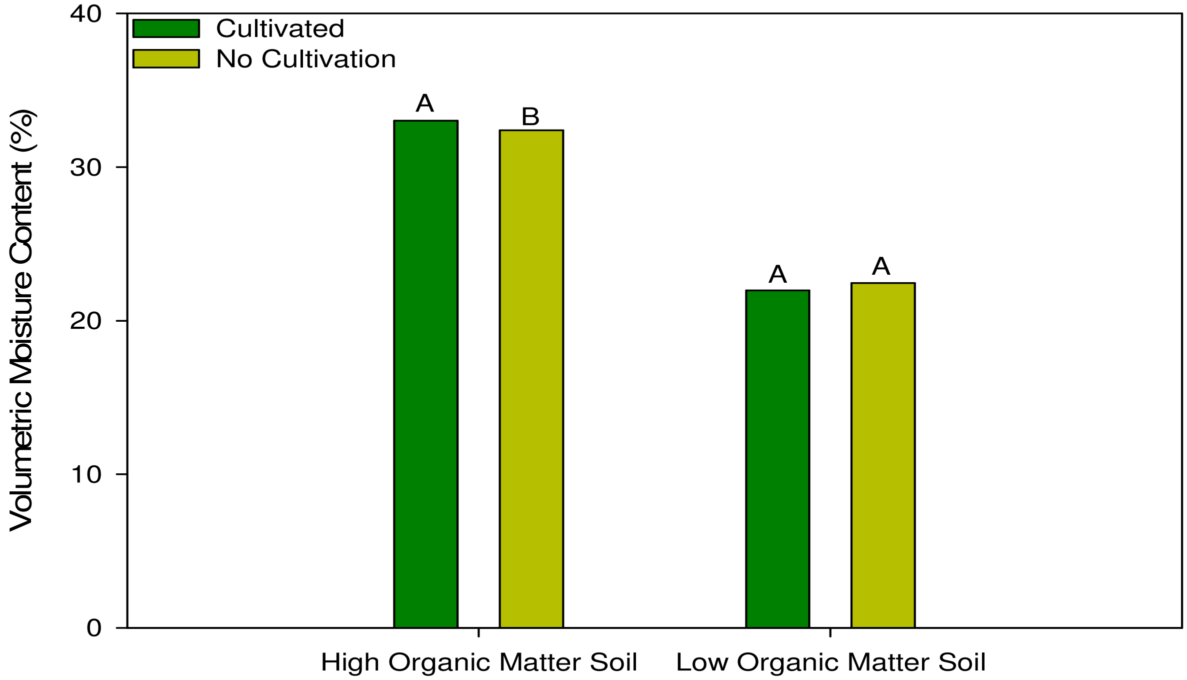

Fig. 3.7. The interaction effect of soil type and cultivation on volumetric moisture content (VMC) values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

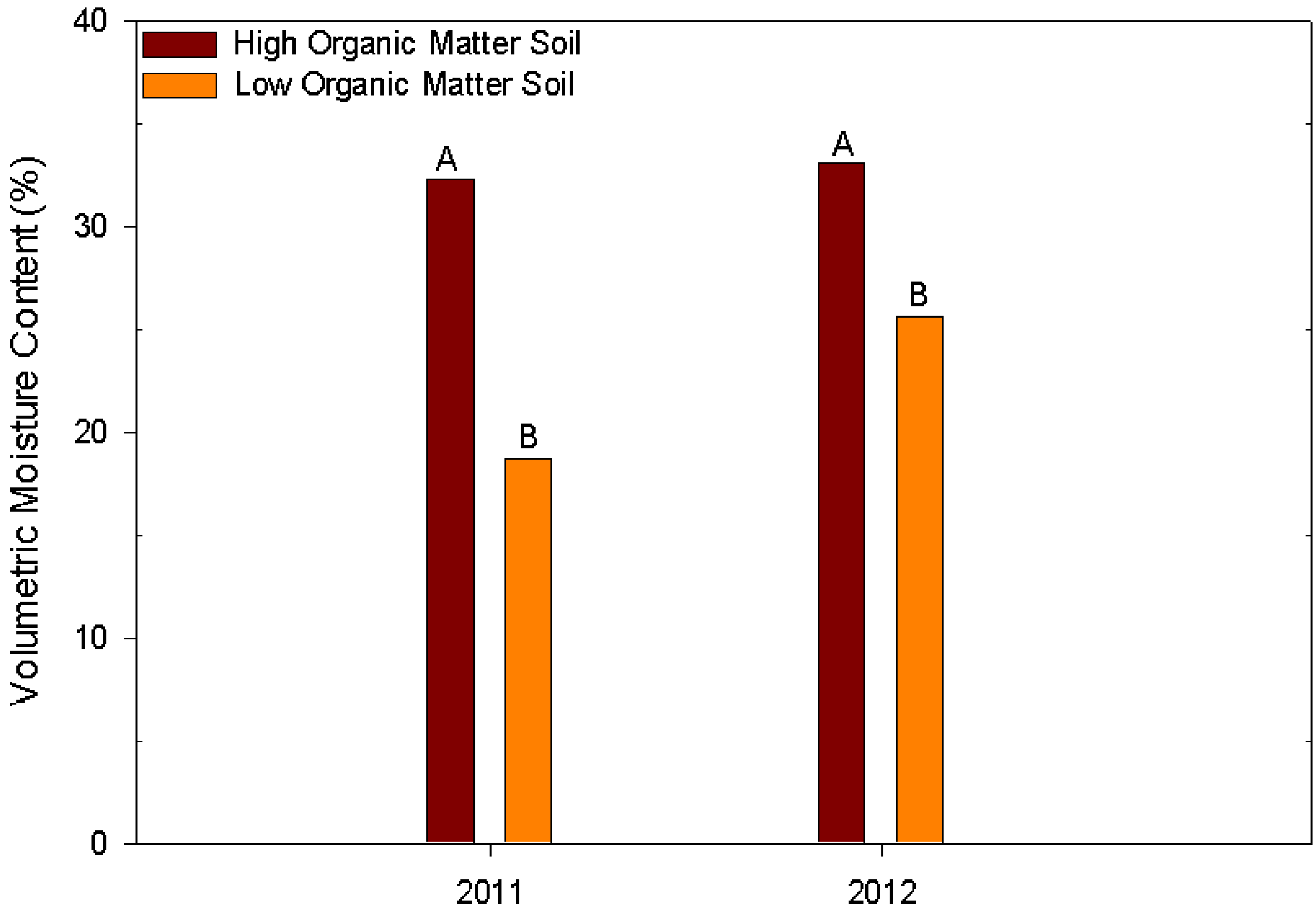

Fig. 3.8. The interaction effect of soil type and year on volumetric moisture content (VMC) values 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test

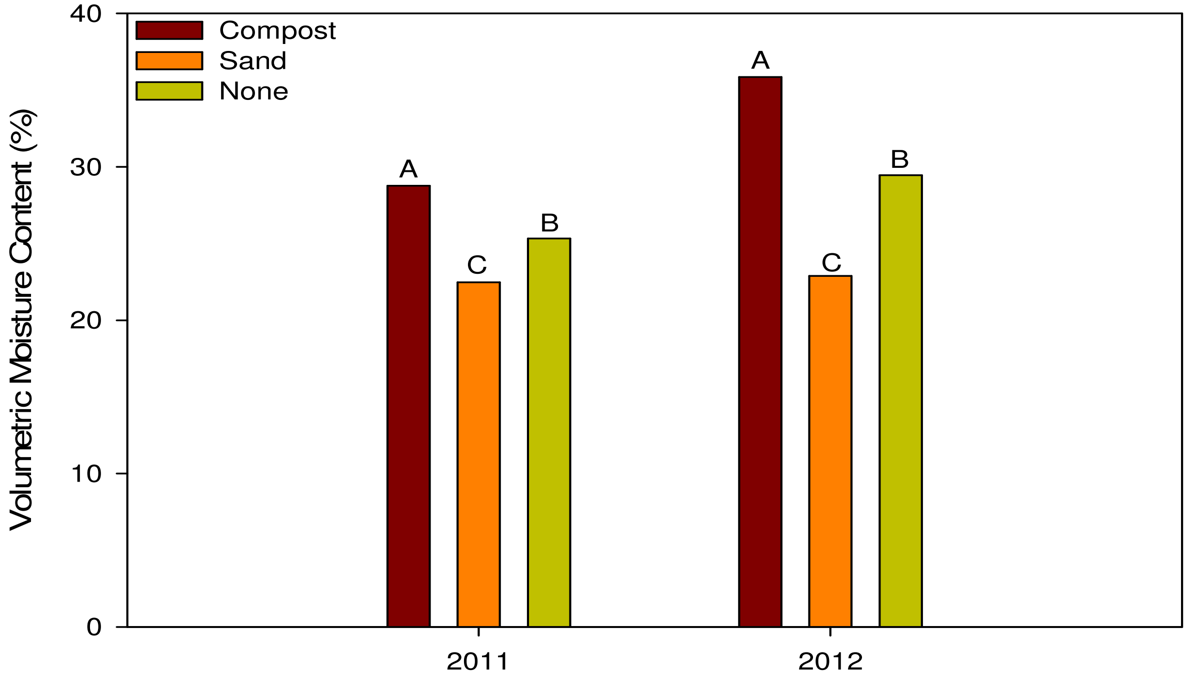

Fig. 3.9. The interaction effect of year and topdressing source on volumetric moisture content (VMC) values 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

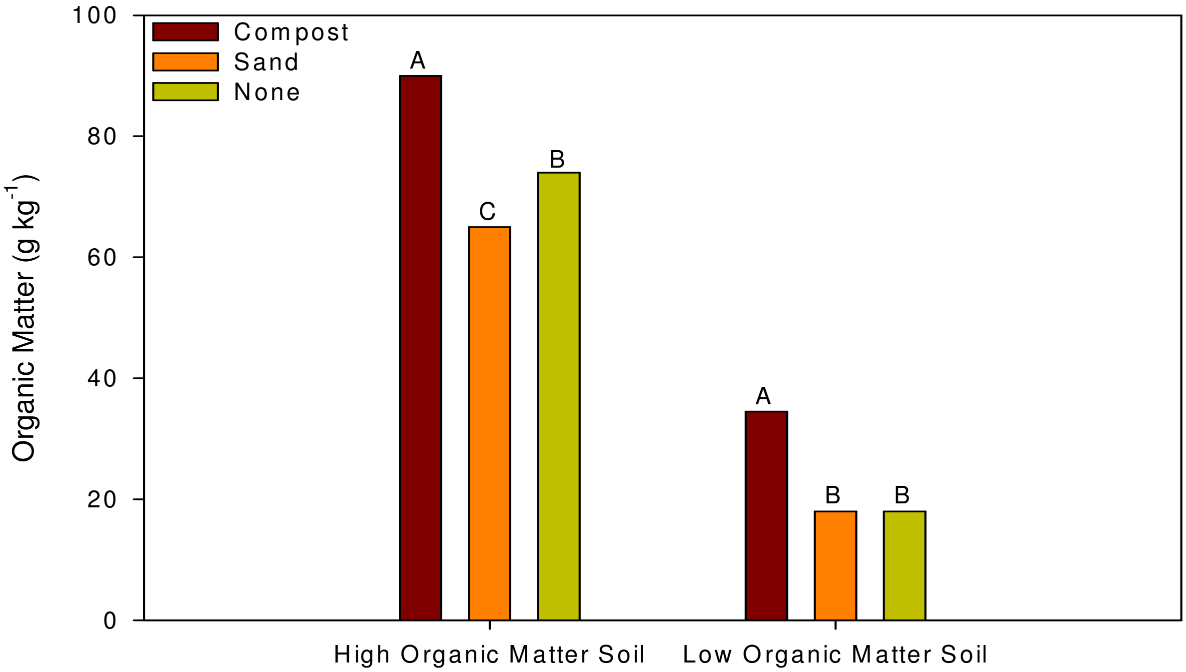

Fig. 3.10. The interaction effect of soil type and topdressing source on percent organic matter, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

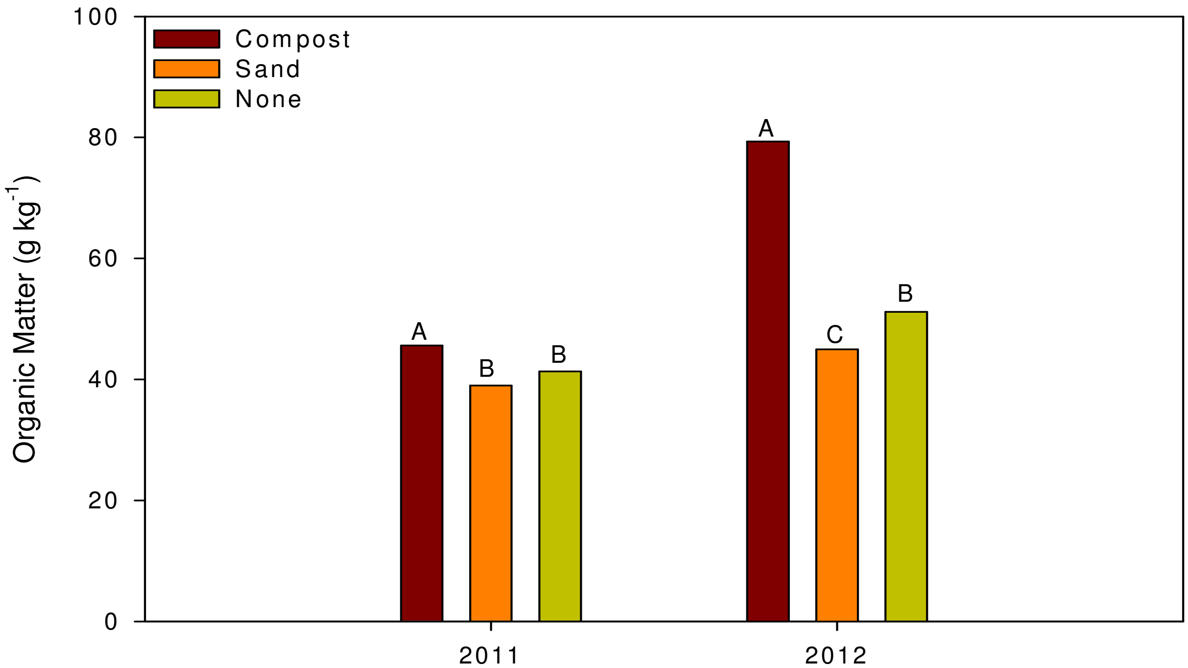

Fig. 3.11. The interaction effect of year and topdressing source on percent organic matter, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

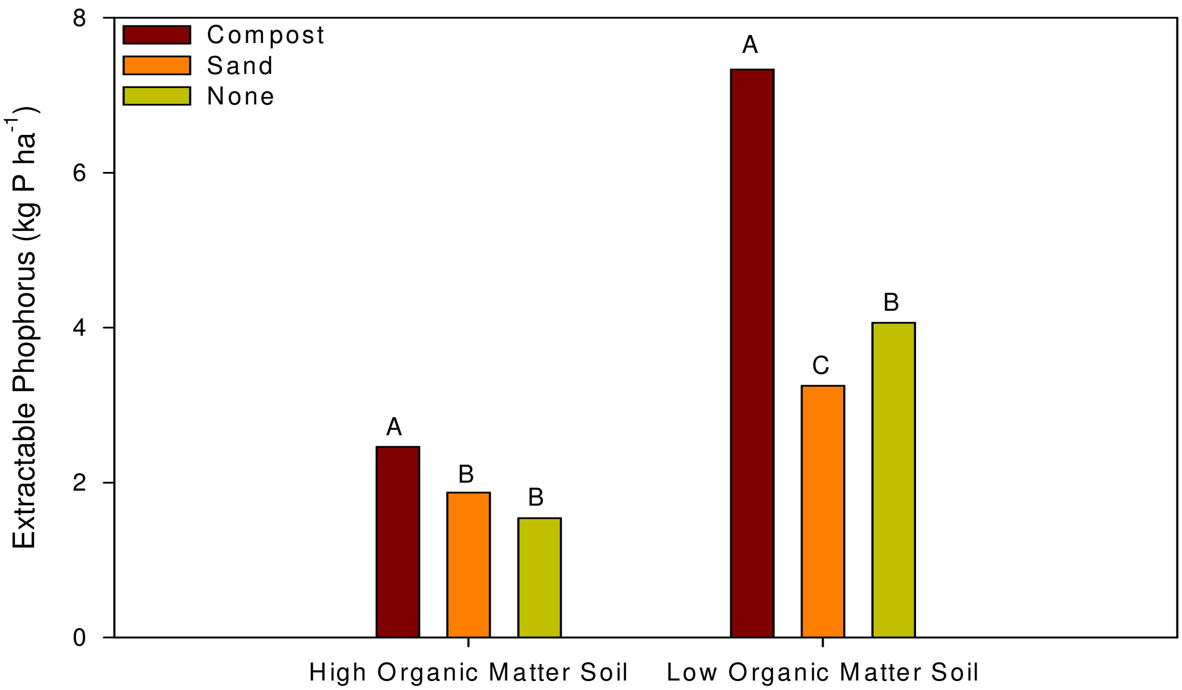

Fig. 3.12. The interaction effect of soil type and topdressing source on phosphorus content, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

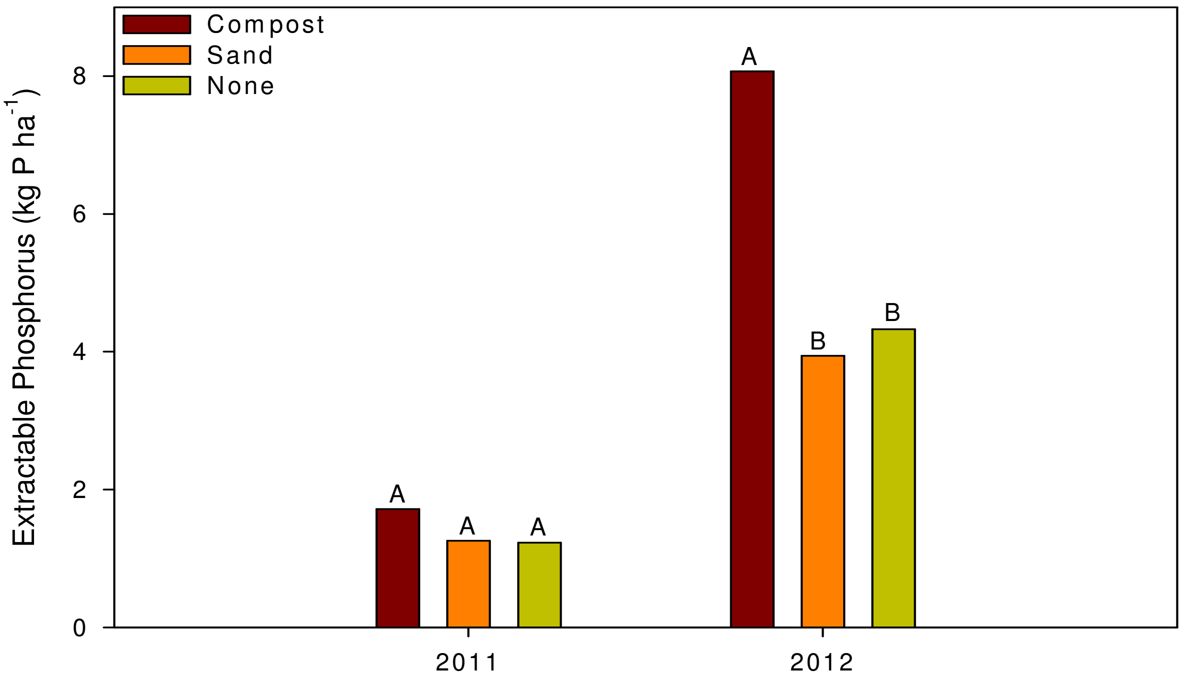

Fig. 3.13. The interaction effect of year and topdressing source on phosphorus content, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

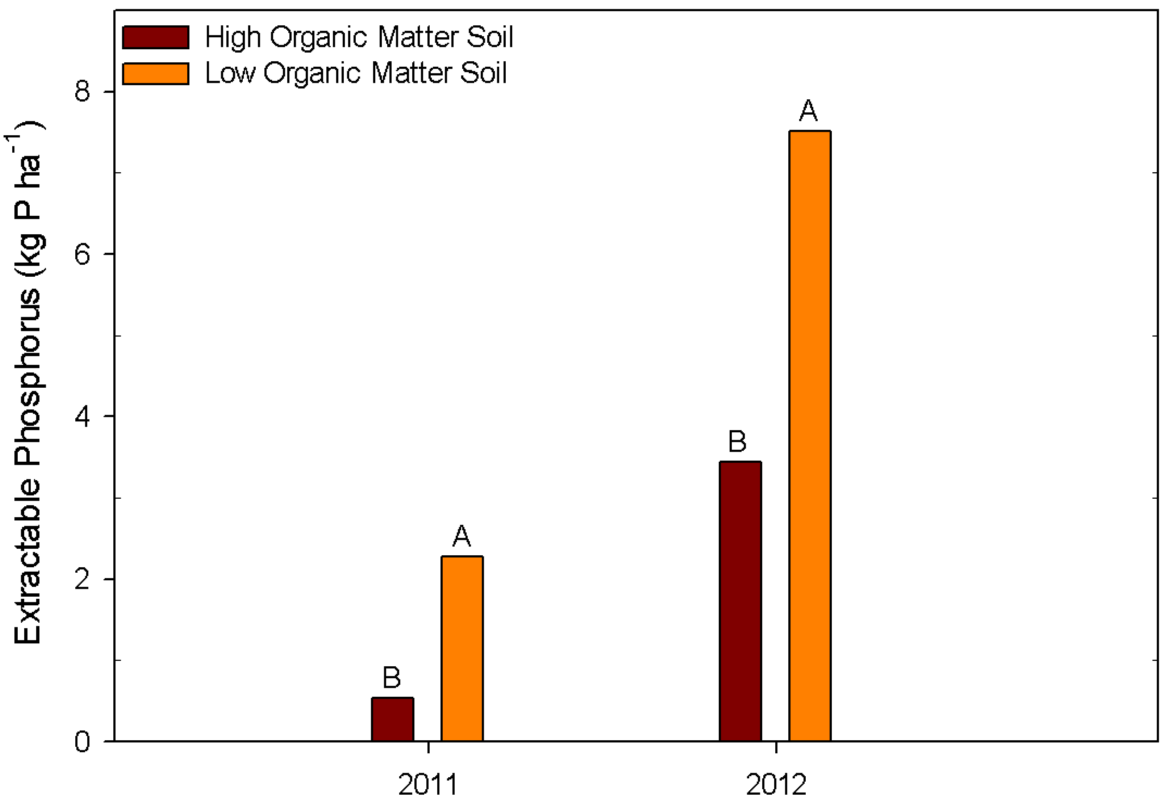

Fig. 3.14. The interaction effect of year and soil type on phosphorus content, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

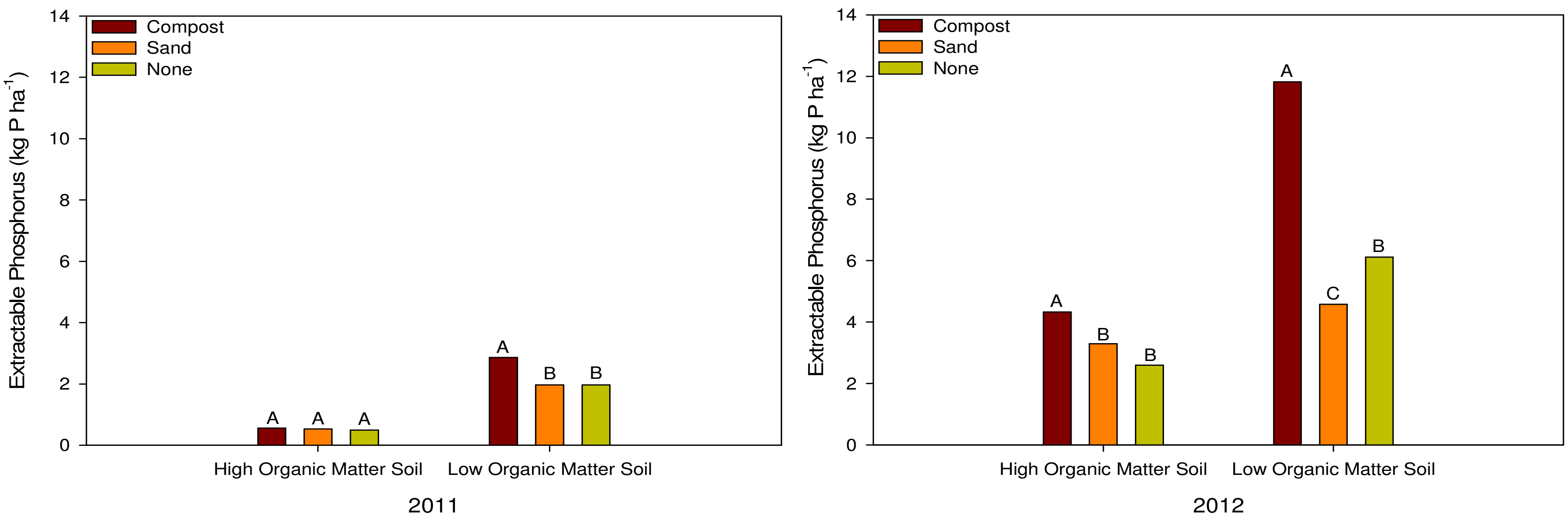

Fig. 3.15. The interaction effect of year, soil type, and topdressing source on phosphorus content, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

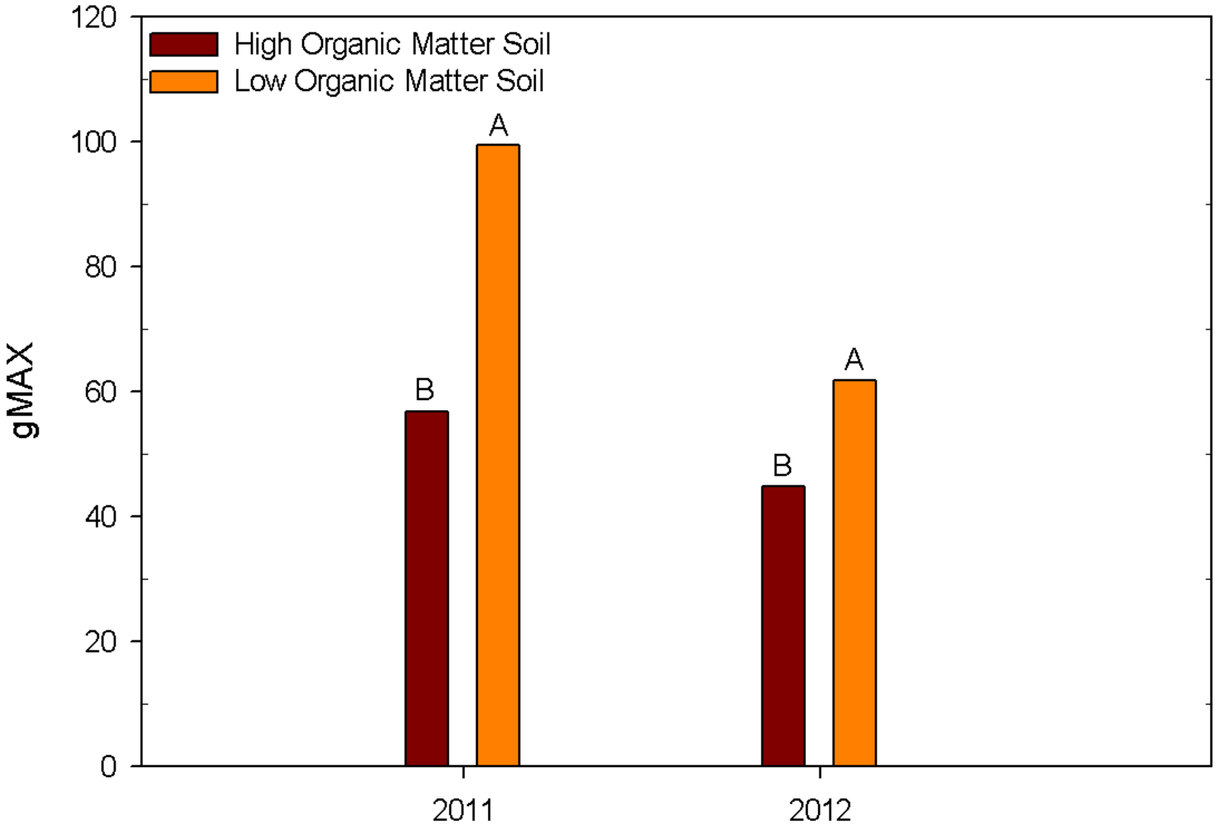

Fig. 3.16. The interaction effect of soil type and year on surface hardness (gMAX) values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

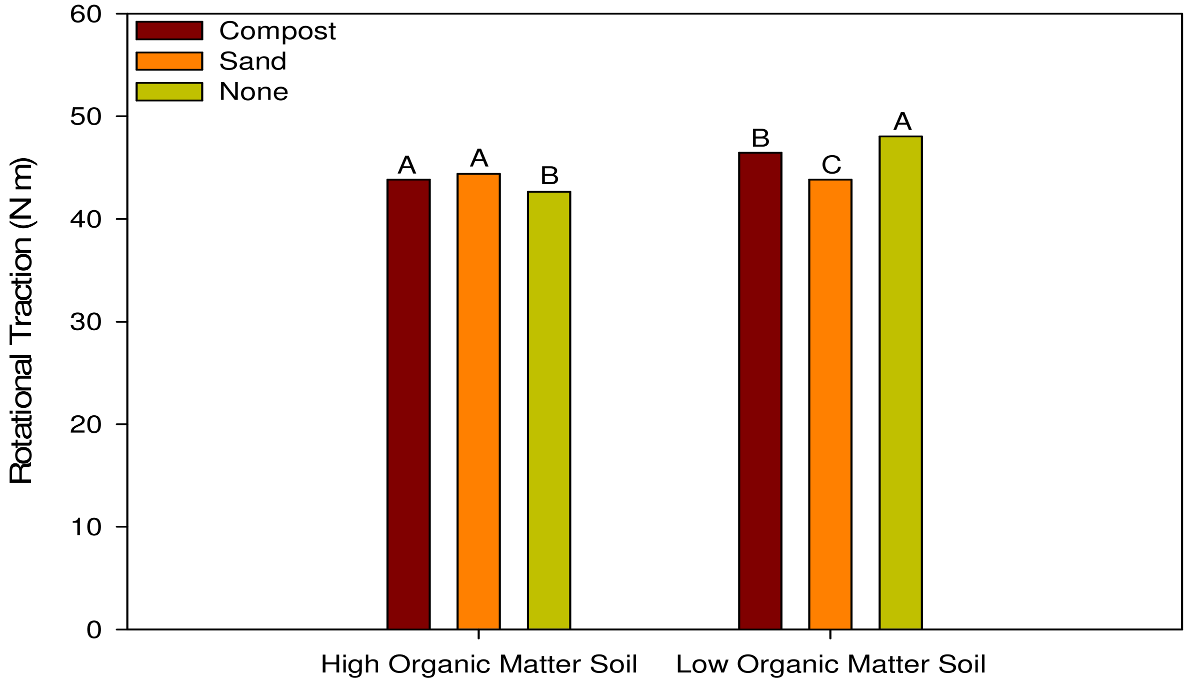

Fig. 3.17. The interaction effect of soil type and topdressing source on rotational traction values, 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

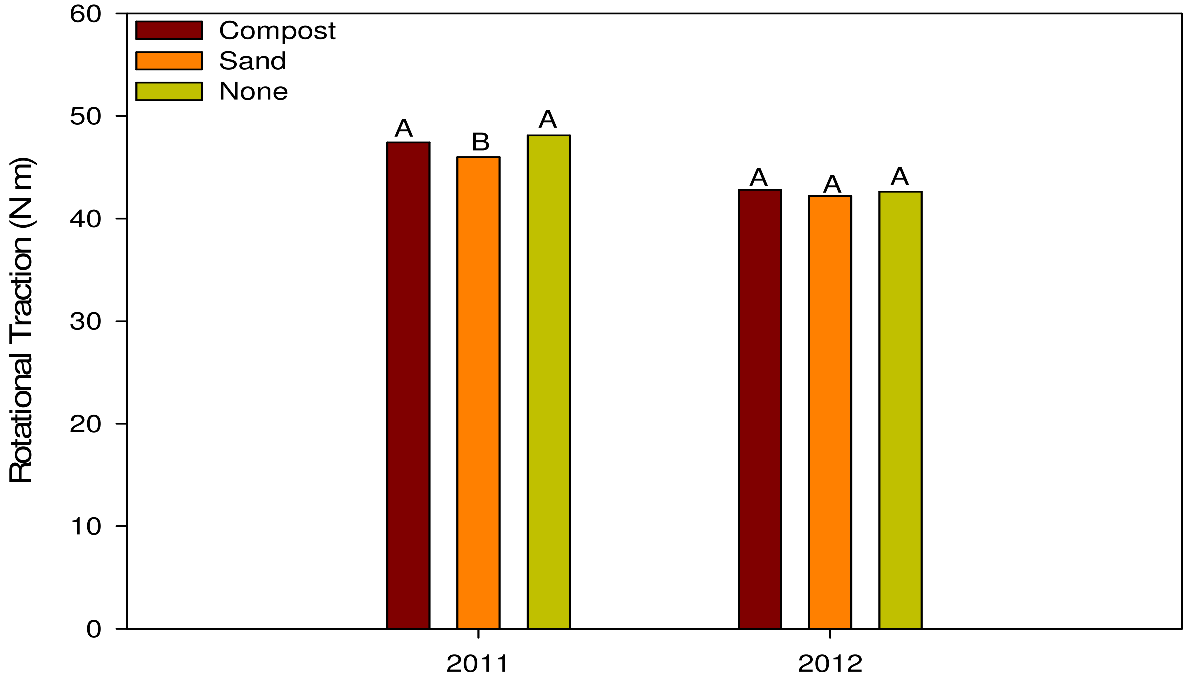

Fig. 3.18. The interaction effect of year and topdressing source on rotational traction values, 2011- 2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

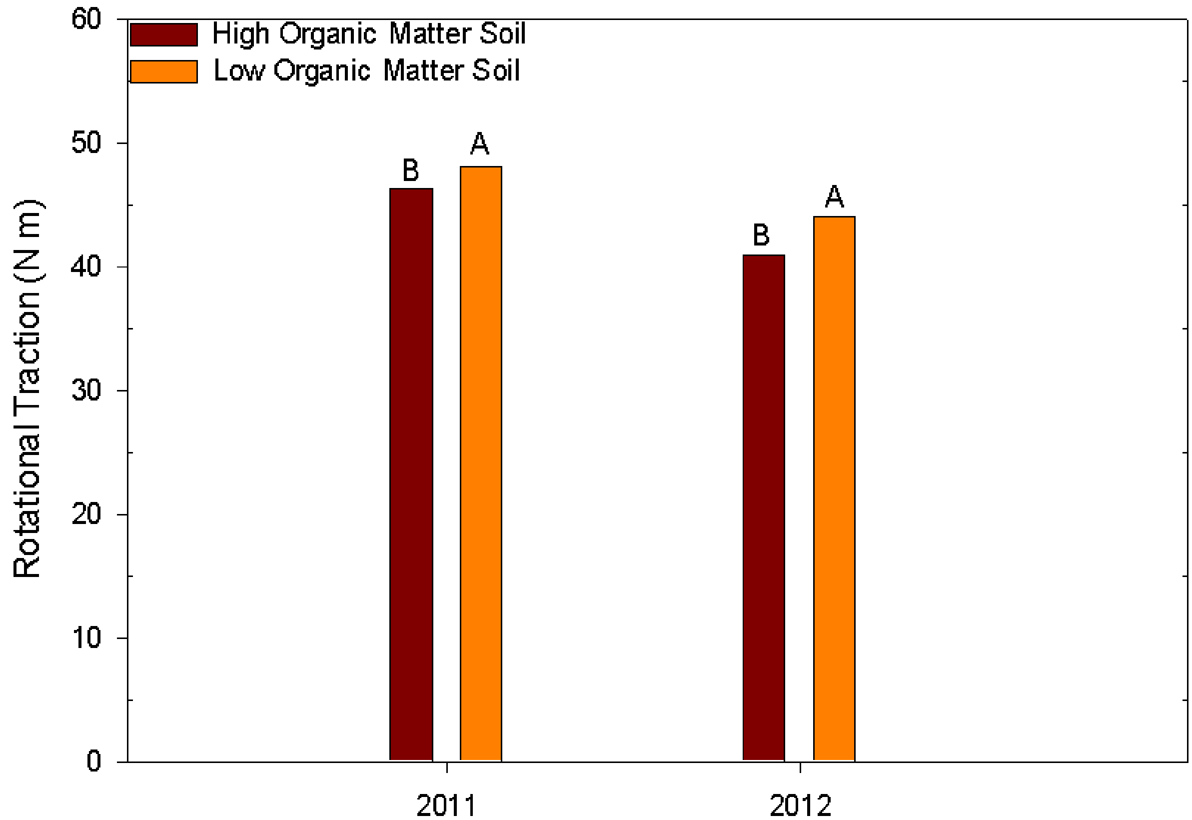

Fig. 3.19. The interaction effect of soil type and year on rotational traction values, 2011-2012. Treatments with the same letter within soil are not significantly different ($p < 0.05$) according to Fisher's LSD test.

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