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ORGANIC MATTER ACCUMULATION IN SAND BASED
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ORGANIC MATTER ACCUMULATION IN SAND BEASED ROOT ZONES

By

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Abstract

Organic Matter Accumulation in Sand Based Root Zones

By

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Decreased macropore space due to organic matter accumulation is often a concern in sand based root zones. The objective of this study was to evaluate organic matter accumulation based on two different root zones and mowing practices. A secondary objective was to compare which organic matter analysis method (loss on ignition (LOI), Walkley-Black (WB), and Carbon/Nitrogen Analyzer (CN)) was most suitable for high sand content root zones containing small percentages of organic matter. The experiments were conducted at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI. The experimental design was a RCBD in a 2 x 2 factorial, with two root zones and two mowing practices. Soil samples where collected at experimental plots at three depths and four sampling dates. Results indicate that root zone and mowing practice had very little effect on the accumulation of organic matter in the sand based root zones. The LOI method when compared to the CN method and the WB method always reported a higher organic matter content with in the soil or thatch. CN method and the WB method had comparable results throughout in this study. The three testing procedures used in this study determined different values for the same samples, therefore it is extremely important to use the same procedure when measuring organic matter concentrations and comparing them to other data or root zones concentrations over time.

Dedicated to my most patient wife Amber

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Introduction and Literature Review

Athletic fields are used every day by athletes all over the world. Turf management of athletic fields can be difficult due to changes in weather and overuse by athletes. A playing surface that meets all demands for those who are involved in the sport is critical.

The best playing surfaces, whether for golf, soccer, or football, have one thing in common; they all have high sand based root zones. An athletic field must provide firm footing, adequate resiliency on impact, and resistance to tearing during play (Henderson 2001). Athletic fields must also drain well and resist the compacting effects of severe traffic (Turgeon, 1991). Sand based root zones for athletic fields have been in use since the first one was constructed in Puyallup, Washington in 1965 (Goss 1965).

Athletic fields are subjected to intense traffic under all types of weather and soil moisture conditions (Beard 1973). Some of the greatest challenges to the turf manager where cool season grasses are used are maintaining surface stability and turf cover throughout a playing season. Many sporting events take place in the early spring and late fall when the cool season turfgrass is dormant. This is also the time of year when excessive soil moisture could occur under excess precipitation and slow evapotranspiration rates. With the turfgrass in or near dormancy and wet soil conditions present, root zones must be designed to provide drainage and stability. Proper drainage and stability ensures the safest playing conditions for athletes.

Stability of sand root zones in athletic fields has been an area of research for many years. People have used different artificial amendments and sand soil mixtures to gain stability in sand root zones while maintaining good infiltration capabilities (Henderson et al. 2005). Stability and infiltration can be achieved in many ways, but maintaining water infiltration rates throughout the life of the root zone has proven to be difficult due to loss of macropore space. Root zone selection is very important when drainage and stability are a concern. Henderson et al., (2005) introduced a root zone mixture of approximately 90% well graded sand and 10% silt/clay (90/10). Through his work it was determined that a root zone mixture of 75 percent sand and 25 percent soil on a volume basis balanced soil surface stability and water infiltration and permeability. Since than, many Michigan fields are choosing the 90/10 root zone for their athletic fields.

Saturated hydraulic conductivity decreases 30-40% from the initial within two years after establishment on high sand root zones (Waddington et al. 1974). The causes for decreased infiltration rates are not completely understood, but turf grass roots, other plant parts, contamination of the root zone, compaction, and the accumulation of organic matter may be some of the causes.

The accumulation of organic matter in sand root zones is cause for concern because of its potential role in decreasing macropore space within a root zone. O'Brian and Hartwiger (2003) wrote that 4 percent organic matter content in the top two inches of a sand based putting green is a "red flag". Gaussoin et al. (2007) did not measure organic matter accumulation specifically, but did find that a decrease in pore size contributes directly to a decrease in infiltration rates on sand root zone putting greens over time; infiltration differences were greater in the top portion of the root zone. Qian et al., (2003) saw a faster increase of soil organic carbon in the top 20mm compared to depths below in a clay loam soil. Once macropore space has been altered, drainage and root growth will change due to a change in pore space continuity through the soil profile.

All factors that contribute to organic matter accumulation in turfgrass stands are not known. Carrow (2003) listed possible organic matter accumulation factors as; prolonged cool temperatures when microbial activity may be down, aggressive cultivars of turf species, poor air drainage that allows a soil surface to stay moist, inadequate topdressing, direct addition of organic substance such as organic fertilizers, acidic pH, high nitrogen rates, and low earth worm activity. Qian et al. (2003) found that clippings returned to a loam soil increased soil organic carbon over time. He also reported that treatments with low nitrogen inputs and harvesting clippings did not increase soil organic carbon. It is unknown what the effects are on organic matter accumulation when clippings are returned or harvested from sand root zones. Kerek et al. showed that over time organic matter increases along with microbial populations.

Organic matter accumulation rate in well graded sand root zones and 90/10 root zones is largely unknown. Gaussoin et al. (2007) found that sand with 5 percent soil and 15 percent peat and sand with 20 percent peat decreases in water infiltration at the same rate over time. Organic matter accumulation was not measured to account for decreased water infiltration. Investigating a well graded sand root zone and a well graded sand root zone with 10% silt and clay for organic matter accumulation could be important to turf managers. Understanding how specific root zones accumulate organic matter could help turf managers create better maintenance plan for long term care of macro pore space in their sand based root zones.

Accuracy when testing organic matter accumulation could benefit turf managers by enabling them to better manage their specific sand root zone. Several methods exist to test organic matter with varying degrees of accuracy and precision, but have not been compared to each other on a homogenous root zone like a sand based athletic field. The use of homogenous root zones should allow for consistent and accurate results to compare different organic matter testing methods. Comparisons between organic matter testing methods have never been done on homogeneous sand root zones. An industry standard for testing organic matter accumulation would benefit field managers in comparing organic matter content in root zones under different management systems across the industry. Given that organic matter accumulates over time, it is critical when measuring the percentage of organic matter that a technique to determine consistent results be used.

Three very common procedures for determining organic matter or organic carbon are Loss on Ignition (LOI) (Storer 1984), wet oxidation with the Walkley and Black procedure (WB) (Walkley and Black 1934) and Carbon/Nitrogen analyzers (CN) (Sollins et al.1999). Currently LOI is the most commonly used procedure due to the ease of preparation of the soil samples and speed at which one can analyze organic matter content (Sollins et al. 1999). Some laboratories are capable of processing up to 1600 samples per day (Storer 1984). LOI methods are also increasing in preference when compared to wet oxidation methods due to the concerns with the disposal and health risks associated with the use of chromic acid which produce chromium compounds known to be toxic and carcinogenic (Combs and Nathan 1998).

A comparison of LOI (850 and 375 degrees Celsius) and a modified WB were performed on 117 upland, 22 lowland and 11 organic soils of North Wales. Results from LOI at 850 and 375 degrees Celsius were correlated with both temperatures, and use of the lower temperature is the preferred procedure (Ball 1964) because it is also understood that heating the soil samples over 500 degrees Celsius can volatilize substances other than organic materials, such as the release of CO_2 from calcium carbonates ($CaCO_3$) and other volatile substances. However, maintaining soil temperatures under 500 degrees Celsius will not affect the organic matter results (Ball 1964, Ben-Dor and Banin1989, and Jackson 1958). LOI at 430 degrees Celsius was compared to WB method on 17 British soils containing 9 to 36.5 percent $CaCO_3$: the results were similar indicating no interference from the carbonates (Davies 1974). Thus, based on the fact that soils high in $CaCO_3$ and heated over 500 degrees Celsius can report falsely higher organic matter percentages, it is important to use a temperature during analysis procedures that will result in determination of accurate organic matter percentages.

WB procedure uses chromic acid oxidation on easily oxidizable carbon. The method uses heat of dilution of concentrated H_2SO_4 to drive the oxidation of carbon in organic matter to CO_2 and measures the unreduced $Cr_2O_7^{2-}$ using a reverse titration procedure to measure total carbon that was lost as CO_2 . Walkley and Black (1934) recovered 60 to 86 percent of the organic C in the soils they studied. As a result of this and other work, a recovery factor of 77 percent is commonly used to convert "easily oxidizable" organic C to total organic C (Combs and Nathan 1998). WB is not recommended very often anymore due to the potential for underestimating soil carbon by 20-30 percent (Nelson and Sommers 1982), but it is unknown what the results would be in homogenous root zones.

CN is a technique that is used to measure total carbon in the soil through high-temperature multiple-sample dry-combustion analyzers. "The detection limit is 10ppm, and measurements are reproducible to better than ± 0.1% absolute value" (Sollins et al. 1999). With the results of these machines so dependable, it is crucial the other procedures be compared to the results of dry combustion. CN method equipment is very expensive and the price per sample reflects that initial cost, but if there is a correlation between the detection of organic matter concentrations using the CN method and LOI method for sand root zones, soil labs could very quickly give more consistent and accurate percentages of root zone organic matter content to turf managers.

All methods for determining soil organic matter content give turf manager's information that can help them manage their specific situation. All of the current procedures have either some major assumptions associated with their use or have different time and sample cost restraints. Comparing the organic matter procedures with the turf manager and their specific root zone as an objective of this research, can offer better information for future management. Determining the best procedure for turf managers to use is crucial for the future in dealing with organic layers and accumulation in the root zone if expectations for athletic fields continue to rise.

Hypothesis:

Root zone organic matter content will increase at a greater rate in plots that have clippings returned as the mowing practice.

Objectives of this research were:

1. Evaluate organic matter accumulation changes in Kentucky bluegrass turf over 3 growing seasons grown in two root zone mixtures with clippings removed or returned (mowing practice).

2. Compare organic matter determination methods (LOI, WB, CN) in Kentucky bluegrass grown on two root zone mixtures with clippings removed or returned.

Materials and Methods

Research was initiated June 2004 at the Hancock Turfgrass Research Center (HTRC) at Michigan State University and continued through fall of 2006. Modules (1.2 x 1.2 m) made of high-density polyethylene plastic (Greentech, Roswell, GA) were filled and compacted with fine gravel and root zone. A total of 48 modules were used. Four modules were grouped together to produce one plot for a total of 12 plots. The design was a randomized complete block design. The treatments consisted of combinations of two types of root zone mixtures and two different mowing techniques and three replications (2*2*3).

The first root zone mixture consisted of well-graded sand and the second root zone was a blend of well-graded sand and Oshtemo Sandy Loam (Coarse-loamy, mixed, mesic Typic Hapludalf) topsoil from combined to produce a mixture of was 90 % sand and 10 % silt and clay. All materials were obtained from Great Lakes Gravel in Grand Ledge, MI. A particle size analysis for all materials is presented in Table 1.

Ten centimeters of fine gravel was added to the bottom of each module. Twenty centimeters of either of the two root zone mixtures was placed into the modules over the fine gravel layer. A corrugated waxed paper divider (30 cm high) was used to separate each root zone treatment. The modules were seeded in June 2004 at a rate of 634 g /100 m^2 with an equal blend of Kentucky bluegrass cultivars(P-105, Midnight, Rugby II, and Showcase) using a shaker bottle containing a pre-weighed amount of seed. Irrigation was applied as needed to initiate germination and to prevent wilt using an automated irrigation system. The

Table 1. Percent passing of fine gravel, sand/topsoil mixture, and sand that was used for root zone mixtures for Kentucky bluegrass, 2004-2006, HTRC East Lansing, MI

Mesh size (mm)	4.75-9.5	2-4.75	1-2	0.5-1.0	0.25-0.5	0.1-0.25	.05-0.1	Silt	Clay
Fine Gravel	1.1	36.3	35.6	23.1	2	1.8	0	0	0
Sand-Topsoil	0	0	13.7	24.8	37.3	16	1.4	2.7	4.1
Sand	0	0	15.3	28.9	40.4	13.2	0.2	0.9	1

modules were fertilized according to the schedule shown in Table 2. At least once a week during the growing season the turf was mowed at 5 cm height, using a walk-behind Honda HR 21" rotary mower (Honda Motor Co., Gardena, CA) during the growing season with two different types of industry standard mowing techniques. Mowing practices that are used for athletic fields are harvesting clippings (remove clippings) or returning clippings. In 2004, it was observed that the grass was growing at a faster rate on treatments with clippings returned. In order to determine if clippings may affect organic matter accumulation results, wet clipping weights were recorded in 2005 and 2006.

To ensure clippings were not collected or returned in the wrong plot, a 0.5 m band was mowed around each treatment using the same mowing practice that the plot specified (clippings returned or clippings removed). Once the band was mowed the remaining area of each plot was then mowed and a modified chute and paper bag (11.4 x 19.6 cm) received the clippings for both mowing treatments. Fresh weights were recorded immediately after mowing. Clippings were then returned to proper treatments and spread evenly throughout plot area from which they had been harvested.

In November of 2004, 2005 and 2006 and April 2006 soil samples were taken for organic matter analysis. Thatch samples were also collected in fall 2005, 2006, and April of 2006. To ensure that samples were not taken in the same place twice, each module was divided into quadrants each of which was assigned a number 1-4. Each plot was divided into 16 subplots (n = 4 sample dates). Samples were collected using a 3.2 cm diameter soil probe to a depth of

Table 2. Fertilizer application dates, rates, and materials on Kentucky bluegrass, 2004-2006, HTRC East lansing, MI

	Date	Rate (kg Nitrogen/ha)	N-P-K
2004			
	3-Jun	24.5	13-26-12
	3-Jun	49.0	37-0-0 polyon
	7-Jul	24.5	13-26-12
	16-Jul	24.5	46-0-0
	23-Jul	24.5	46-0-0
	2-Aug	24.5	18-6-15
	16-Aug	24.5	18-6-15
	30-Aug	24.5	18-6-15
	13-Sep	24.5	18-6-15
	27-Sep	24.5	18-6-15
	11-Oct	24.5	18-6-15
	25-Oct	24.5	18-6-15
2005			
	14-Apr	24.5	18-6-15
	15-May	24.5	18-6-15
	8-Jun	24.5	18-6-15
	8-Jun	*	Micronutrients
	8-Jul	24.5	18-6-15
	21-Jul	24.5	25-5-15
	21-Jul	*	Micronutrients
	29-Aug	49.0	25-5-15
	12-Oct	49.0	25-5-15
2006			
	14-Apr	24.5	25-5-15
	10-May	37.0	25-5-15
	14-Jun	49.0	25-5-15
	14-Jun	*	Micronutrients
	29-Jul	37.0	25-5-15
	9-Aug	24.5	25-5-15
	14-Sep	49.0	25-5-15
	10-Oct	24.5	25-5-15

* 12% Magnesium, 12% Sulfer, 0.18% Boron, 0.50% Copper, 12% Iron, 3% Manganese, 1% Zinc at a rate of 24.5 kg fertilizer/ha

12 cm (5 in). The soil cores were than separated from the thatch and shoots and partitioned into three different depths; 0-2.5 cm, 2.5-5 cm and 5-10 cm and placed into separate cardboard soil boxes.

Soil samples were air dried and passed through a 2 mm sieve twice to remove non-soil components such as grass clippings or root masses. Using a soil grinder (Brinkmann Instruments Co. Type ZM1, Westbury, NY), soil samples was homogenized for further analysis. Thatch samples were air dried and homogenized using a plant grinder (Thomas Scientific Laboratory Mill Model 4, Swedesboro, NJ). Organic matter analyses were done using three methods: Loss on Ignition (LOI) (Storer 1984), the Walkley-Black method (WB) (Walkley and Black et al 1934) and Carbon/Nitrogen analyzer (CN) (Carlo Erba Instruments NA 1500 Series 2, Milan, Italy).

$CaCO_3$ equivalent procedures were performed to both types of root zone mixtures to determine amounts of $CaCO_3$ present (SCS 1972). Results of $CaCO_3$ testing showed a high concentration of $CaCO_3$ in both root zone mixtures. Due to known high $CaCO_3$ content in the soil, LOI was performed at 360 degrees Celsius and samples where heated for two hours (Schulte et al 1991). To insure that there was no $CaCO_3$ interference with the concentration of organic matter, random samples were soaked in 4N HCL acid to remove $CaCO_3$. The HCl reacts with the $CaCO_3$ and releases the carbon as CO_2. Samples from the same treatments were than tested using LOI and compared to results without the removal of $CaCO_3$. LOI at low temp showed no $CaCO_3$ interference.

All samples that were prepared for the Carbon/Nitrogen analyzer were oxidized with 4N HCl acid prior to sampling. This allows the Carbon/Nitrogen analyzer to measure the remaining carbon in the soil without $CaCO_3$ interference. Five g samples were soaked for 48 hours on a stir tray in 50 ml plastic sampling tubes. All samples were also stirred vigorously three times throughout the 48 hours to be sure all $CaCO_3$ had been oxidized. Samples were than centrifuged and the remaining acid was decanted. Thirty ml H_2O was than added to each sample and stirred vigorously. Samples were again centrifuged and the excess water was decanted. Samples were then rinsed into 50 ml weigh boats and dried at 65 C. Approximately 45 mg of root zone mixture and 10 mg of thatch were put into tin foil capsules. The foil capsules were placed into the CN analyzer with a check every 12 samples.

The three organic matter testing procedures selected for this study differ on how organic matter is measured or calculated. In order to compare the WB method and CN method to LOI method all were converted to percent organic matter. Percent carbon for WB is calculated with assumptions on how much organic carbon is easily oxidizable. All percent carbon data from CN method and WB method was converted to organic matter content by dividing by 0.63. The conversion factor of 0.63 was determined by the LOI method by comparing a known soil used as a check sample throughout the analysis of samples.

Statistical analysis was performed on the soil samples as a split-split plot design using Proc Mixed procedure of SAS (SAS 9.1 Cary, NC). The split-split was derived from the three soil depths, three organic matter testing procedures, two mowing practices, and two root zones. Means were separated using Fisher's LSD procedure at the 0.1 level of probability. The thatch samples were analyzed separately using Proc Mixed procedure of SAS. The organic matter content in the thatch was much higher than the soils, allowing for too much variability when statistical analysis was applied when soil and thatch were compared to one another. Therefore statistical analysis on the thatch was separated from the root zone mixture samples and analyzed by itself using Proc Mixed procedure of SAS.

Results and Discussion

Clipping Yield

No significant differences in clipping yield were observed between the two root zone mixtures (Table 3). Kentucky bluegrass clipping yields differed due to mowing practice (Table 3). Significantly greater clipping yields were observed for plots to which clippings were returned in comparison to plots which had clippings removed in both the summer of 2005 and 2006 (Table 3). Grass grew faster in plots with clippings returned, suggesting that clippings could serve as a continuous organic source of nutrients in addition to the fertilizer that was applied to both mowing treatments.

Thatch Organic Matter

Table 4 effects of analysis methods in thatch organic matter concentrations were shown in organic matter analysis method, root zone mixture, and mowing practices.

In fall 2005, there were differences in thatch organic matter between root zone mixtures (Table 5). These differences did not continue in later sampling dates. An explanation for the difference in fall 2005 is not clear. The differences are very small and may have little practical meaning.

Thatch organic matter differences between mowing practice occurred in the spring and fall of 2006 (Table 5). In both instances clippings returned had statistically more organic matter. Decomposition of the clippings that were within

Table 3. Analysis of variance for clipping yields and effects of mowing practice on clipping yields in Kentucky bluegrass for entire growing season 2005 and 2006, HTRC East Lansing, MI

Source of Variation	DF	2005	2006
Root zone mixture	1	NS	NS
Mowing Practice	1	*	*
Root zone mixture and Mowing Practice	1	NS	NS
Mowing Practice Mean		—— g ——	
Clippings Removed		52	80
Clippings Returned		137	172
Significance		*	*

* indicates significance at α 0.10 probability level

NS indicates nonsignificance at α 0.10 probability level

Table 4. Analysis of variance for organic matter concentrations in Kentucky bluegrass thatch, 2005-2006 HTRC East Lansing, MI.

Source of Variation	DF	Fall 2005	Spring 2006	Fall 2006
Organic matter analysis method (Method)	2	*	*	*
Root zone mixture (RZM)	1	*	NS	NS
Mowing practice (MP)	1	NS	*	*
RZM*MP	1	NS	NS	NS
RZM*Method	2	NS	NS	NS
MP*Method	2	NS	NS	NS
RZM*MP*Method	2	NS	NS	NS

* indicates significance at α 0.10 probability level

NS indicates nonsignificance at the α 0.10 probability level

Table 5. Thatch organic matter content based on analysis method, root zone mixture, and mowing practice on Kentucky bluegrass, 2005-2006, HTRC East Lansing, MI grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

	Fall 2005	Spring 2006	Fall 2006
Thatch Organic Matter Analysis Method		%	
Walkley Black	10.2	14.5	11.3
Loss on Ignition	15.9	21.3	18.8
Carbon/Nitrogen Analyzer	8.4	10.6	11.6
LSD	0.9	1.5	1.8
Thatch Root zone mixture			
90/10 (sand/silt and clay)	12.0	16.2	14.0
Sand	11.0	14.7	13.8
Significance	*	NS	NS
Mowing Practice			
Clippings Returned	11.0	16.4	15.0
Clippings Removed	12.0	14.5	12.8
Significance	NS	*	*

* indicates significance at α 0.10 probability level

NS indicates nonsignificance at α 0.10 probability level the thatch is a viable explanation for the differences present in thatch organic matter content between the two mowing practices for thatch organic matter. Total thatch depth was also measured to account for total thatch accumulation between all factors. There was no significance for total thatch depth.

Detection of thatch organic matter concentrations differed between the three analysis methods tested in the fall 2005, 2006 and spring 2006 (Table 5). In all instances the LOI method reported the highest amount of organic matter. On two of the three dates, the CN method showed the lowest amount of organic matter. The WB method and the CN method were not statistically different in the fall of 2006, possibly allowing for direct comparison between methods. CN method results showed a consistent increase in organic matter accumulation over time, while WB method and LOI method both showed an increase in fall 2005 and than a decrease in fall 2006. CN method appears to be most consistent with organic matter concentrations.

Soil Organic Matter

Table 6 effects of analysis methods for soil organic matter levels were shown in all independent variables and some two-way interactions.

Organic matter in root zone mixtures was significantly different for all sampling dates, 2004-2006 (Table 7). Organic matter content in 90/10 (sand/silt and clay) root zone mixture always had a statistically greater content of organic matter than the sand root zone mixture (Table 7). The consistent difference in organic matter between these two root zone mixtures was probably due to the organic matter already present in the 25 percent topsoil that was mixed with the

Table 6. Analysis of variance for organic matter concentrations in Kentucky bluegrass root zone, 2004-2006 HTRC East Lansing, MI.

Source of Variation	DF	Fall 2004	Fall 2005	Spring 06	Fall 2006
Organic Matter Analysis Method (Method)	2	*	*	*	*
Root zone mixture (RZM)	1	*	*	*	*
Method*RZM	2	*	*	*	*
Mowing Practice (MP)	1	NS	NS	NS	*
Method*MP	2	*	*	NS	*
RZM*MP	1	NS	NS	NS	NS
Method*RZM*MP	2	NS	NS	NS	NS
Soil Depth (SD)	2	*	*	*	*
Method*SD	4	*	NS	NS	*
RZM*SD	2	NS	NS	*	NS
Method*RZM*SD	4	NS	NS	NS	NS
MP*SD	2	NS	NS	NS	NS
Method*MP*SD	4	NS	NS	NS	NS
RZM*MP*SD	2	*	NS	*	NS
Method*RZM*MP*SD	4	NS	NS	NS	NS

* indicates significance at α 0.10 probability level

NS indicates nonsignificance at α 0.10 probability level

Table 7. Root zone organic matter content based on analysis method, root zone mixture, mowing practice, and soil depth in Kentucky bluegrass , 2004-2006, HTRC East Lansing, MI grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

	Fall 2004	Fall 2005	Spring 2006	Fall 2006
Organic Matter Analysis Method		%		
Walkley Black (WB)	0.29	0.37	0.25	0.28
Loss on Ignition (LOI)	0.45	0.51	0.46	0.59
Carbon/Nitrogen Analzser (CN)	0.23	0.24	0.24	0.28
LSD	0.02	0.02	0.01	0.01
Root zone mixture				
90/10 (sand/silt and clay)	0.41	0.46	0.41	0.45
Sand	0.23	0.28	0.23	0.32
Significance	*	*	*	*
Mowing Practice				
Clippings Returned	0.32	0.38	0.32	0.37
Clippings Removed	0.32	0.36	0.32	0.40
Significance	NS	NS	NS	*
Soil depth				
0-2.5cm	0.39	0.45	0.42	0.47
2.5-5cm	0.30	0.36	0.28	0.36
5-10cm	0.28	0.31	0.25	0.32
LSD	0.02	0.02	0.01	0.01

* indicates significance at α 0.10 probability level

NS indicates nonsignificance at α 0.10 probaility level sand to create the 90/10 root zone. It is important to note that organic matter did not accumulate at a greater rate in either root zone mixture over time. This suggests that the soil component within the 90/10 root zone had no effect on organic matter accumulation when compared to a root zone of sand.

Mowing practice for soil organic matter was significant in fall of 2006 exclusively (Table 7). Clippings returned had a lower percentage of root zone organic matter. An explanation for the difference is not apparent, but speculation of increased microbial activity with higher amounts of nitrogen from the returned clippings could account for less organic matter accumulation.

Root zone organic matter differences between soil depths occurred for all sample dates, 2004-2006 (Table 7). The organic matter content in the 2.5 cm depth was always greater than the 5 cm depth, which was greater than 10 cm depth. This trend shows that organic matter did accumulated near the surface of a homogeneous root zone before it accumulates deeper within the root zone.

Differences in root zone mixture organic matter content between the organic matter analysis methods used in this research occurred in all sample dates from 2004-2006 (Table 7). In all instances, the LOI method reported the highest amount soil organic matter. The WB method and the CN method were not statistically different for spring and fall of 2006. Data had similar trend to thatch testing method (Table 5) in that LOI method reported greater organic matter content than the WB method and the CN method, while the WB method and the CN method remained comparable.

Organic Matter Analysis Method x Root Zone Type

Root zone organic matter content had differences for all sample dates, 2004-2006 based on organic matter analysis method x root zone type (Table 8). The interaction suggests that the LOI method consistently reports more organic matter for the different soil types of soil than the WB method and the CN method. The 90/10 (sand/silt and clay) root zone was always statistically greater within the same organic matter analysis method when compared to sand. The WB method and the CN method continued to show similar trends in the 2006 sampling year, further showing that direct comparison is an option.

Organic Matter Analysis Method x Mowing Practice

Root zone organic matter content differences between organic matter analysis methods x mowing practice occurred on fall sampling dates 2004-2006 (Table 9). Some differences are present between mowing practice within the same organic matter analysis method, but the WB method was the only one that constantly showed clippings removed had a higher percentage of organic mater. Otherwise, differences are consistent between organic matter analysis methods.

Organic Matter Analysis Method x Root Zone Depth

Soil organic matter differences between organic matter analysis methods x root zone depth occurred in fall 2004 and 2006 (Table 10). The interactions occurring are best explained in the difference in the top 2.5 cm and the LOI method. The LOI method indicated greater organic matter percentages for all depths than the other organic matter testing methods. In all analysis methods

Table 8. Root zone organic matter content based on analysis method x root zone mixture on Kentucky bluegrass, 2004-2006, HTRC East Lansing, MI. grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

Organic Matter Method * Root zone mixture	Fall 2004	Fall 2005	Spring 2006	Fall 2006
		%		
Walkley Black * 90/10	0.35	0.42	0.32	0.33
Walkley Black * Sand	0.22	0.32	0.18	0.23
Loss on Ignition * 90/10	0.59	0.66	0.59	0.70
Loss on Ignition * Sand	0.31	0.36	0.33	0.49
Carbon/Nitrogen Analyzer * 90/10	0.30	0.30	0.31	0.32
Carbon/Nitrogen Analyzer * Sand	0.15	0.17	0.18	0.24
LSD	0.03	0.03	0.02	0.02

significant at the $\alpha = 0.10$ probability level

Table 9. Root zone organic matter content based on analysis method x mowing practice on Kentucky bluegrass, 2004-2006, HTRC East Lansing, MI.grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

Organic Matter Method * Mowing Practice	Fall 2004	Fall 2005	Fall 2006
		%	
Walkley Black * Clippings Returned	0.27	0.34	0.25
Walkley Black * Clippings Removed	0.30	0.40	0.32
Loss on Ignition * Clippings Returned	0.45	0.51	0.59
Loss on Ignition * Clippings Removed	0.44	0.52	0.59
Carbon/Nitrogen Analyzer * Clippings Returned	0.23	0.25	0.27
Carbon/Nitrogen Analyzer * Clippings Removed	0.22	0.22	0.29
LSD	0.03	0.03	0.02

significant at the $\alpha = 0.10$ probability level

Table 10. Root zone organic matter content based on analysis method x soil depth on Kentucky bluegrass, 2004-2006, HTRC East Lansing, MI. grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

Organic Matter Method * Soil Depth	Fall 2004	Fall 2006
	%	
Walkley Black at 2.5cm	0.34	0.36
Walkley Black at 5cm	0.27	0.26
Walkley Black at 10cm	0.25	0.23
Loss on Ignition at 2.5cm	0.56	0.70
Loss on Ignition at 5cm	0.40	0.57
Loss on Ignition at 10cm	0.39	0.51
Carbon/Nitrogen Analyzer at 2.5 cm	0.27	0.36
Carbon/Nitrogen Analyzer at 5cm	0.21	0.27
Carbon/Nitrogen Analyzer at 10cm	0.19	0.22
LSD	0.03	0.02

significant at the $\alpha = 0.10$ probability level

organic matter accumulated from the top of the soil profile and percentages decrease with soil depth.

Root Zone Depth x Root Zone Type

Root zone depth x root zone type interaction indicated differences in soil organic matter in spring 2006 (Table11). The 90/10 root zone had a greater percentage of organic matter than sand. The top 2.5 cm had a greater percentage of organic matter when compared to the deeper depths. It is not understood why the differences were not present before spring of 2006 or after in the fall of 2006.

Hypothesis:

Root zone organic matter content will increase at a greater rate in plots that have clippings returned as the mowing practice.

Objectives of this research were:

1. Evaluate organic matter accumulation changes in Kentucky bluegrass turf over 2.5 years grown in two root zone mixtures with clippings removed or returned (mowing practice).

2. Compare organic matter determination methods (LOI, WB, CN) in Kentucky bluegrass grown on two root zone mixtures with clippings removed or returned.

Conclusions

The hypothesis at the beginning of this study was that organic matter will accumulate more rapidly when clippings are returned. Data for this research did

Table 11. Root zone organic matter content based on soil depth x root zone mixture on Kentucky bluegrass, Spring 2006, HTRC East Lansing, MI. grown in 90 or 100 percent sand root zones and mowed with clippings removed or returned after mowing.

	Spring, 2006
Root zone Mixture * Soil Depth	———%———
90/10 at 2.5cm	0.53
90/10 at 5cm	0.37
90/10 at 10cm	0.33
Sand at 2.5cm	0.32
Sand at 5cm	0.20
Sand at 10cm	0.17
LSD	0.02

significant at the $\alpha = 0.10$ probability level

show an accumulation of organic matter between mowing practices over three growing seasons.

Root zone mixtures and mowing practice had little significance in this study on organic matter concentrations. The root zone mixtures were different throughout, but that was due to the already present organic matter in the topsoil component of the 90/10 (sand/silt and clay). Neither root zone accumulated organic matter at a faster rate than the other. Mowing practice (clippings removed and clippings returned) had little difference in organic matter accumulation. When there was significance (fall 2006) clippings removed had a higher organic matter content. This is probably best explained by a difference in microbial populations between mowing treatments. It was not measured in this research, but clippings returned could provide more nitrogen into the root zone allowing for more microbial activity and break down of organic matter.

The LOI method when compared to the CN method and the WB method always reported a higher organic matter content with in the soil or thatch. The CN method and the WB method had comparable results throughout in this study. Nelson and Sommers (1982) reported that the WB method is not often recommended because it has the potential to underestimate soil carbon by 20-30 percent. When comparing organic matter results using the three testing methods of this research, the LOI method may report an organic matter percentage that is greater than the other two procedures in this study. Of the four sampling dates the root zone organic matter contents reported by the WB method and CN method were significantly different on two of the sampling dates. Of the three methods

WB method and CN method were mostly comparable while the LOI method root zone organic matter concentrations where quit different. In this research the organic matter is relatively young; results may not be comparable on an older sand based root zone that has organic matter that is further along in decomposition. LOI method constantly reported higher values than WB method and CN method, and WB method has limitations to what is oxidized and assumptions that have to be made. The three testing procedures used in this study determined different values for the same samples, therefore it is extremely important to use the same procedure when measuring organic matter concentrations and comparing them to other data or root zones concentrations over time.

References

Ball, D.F. 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in noncalcarous soils. Soil Science 15:84-92

Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice Hall. Englewood Cliffs, NJ.

Ben-Dor, E. and A. Banin. 1989. Determination of organic matter content in arid-zone soils using a simple "loss-on-ignition" method. Communications Soil Science. Plant Analysis. 20: 1675-1695

Carrow, R.N. 2003. Surface Organic Matter in Bentgrass Greens. USGA Turfgrass and the Environment Research Online. September 1. 2(17): p. [1-12].

Combs S.M. and M.V. Nathan. 1998 Soil Organic Matter pages 53-58 in Recommended Chemical Soil Test Procedures for the North Central Region. Missouri Agricultural Experiment Station SB 1001. Chapter 12: 53-58

Davies, B.E. 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Science Society America Proc. 38: 150-151

Gaussion, R.; Sherman, R.; Wit, L.; McClellan, T.; Lewis, J.. 2007. Soil Physical and Chemical Characteristics of Aging Golf Greens. Golf Course Management. January. 75(1):p 161-165.

Goss, R.L. 1965 Football Field Construction. P.4-6. *In* Northwest Turfgrass Topics. Vol. 7, No.3. Dec. 1965. Puyallup, WA.

Henderson, J.J.; Crum, J.R.; Wolff, T.F.; Rogers, J.N. III. 2001. 71st Annual Michigan Turfgrass Conference Proceedings. 30:p. 96-99

Henderson, J. J., J. R. Crum, T. F. Wolff, and J. N. Rogers. 2005. Effects of Particle Size Distribution and Water Content at Compaction on Saturated Hydraulic Conductivity and Strength of High Sand Content Root Zone Materials. Soil Sci. 170 (5): 315-324,

Kerek, M., R.A. Drijber, W.L. Powers, R.C. Shearman, R.E. Gaussoin, and A.M. Striech. 2002. Accumulation of Microbial Biomass within Particulate Organic Matter of Aging Golf Greens. Agron. J. 94:455-461

Jackson, M. L. 1958. Soil Chemical Analysis. Prentice Hall, Inc. Englewood Cliffs, N.J.

Nelson, D.W., and L. E. Sommers. 1982 Total Carbon, organic carbon, and organic matter. Pages 539-579 in A. L. Page, R. H. Miller, and D. R Kenny, editors, Methods of Soil Analysis. ASA Monograph 9. Am.Soc. of Agron., WI

O'Brian, P. and C. Hartwiger. 2003. Aeration and Topdressing for the 21st century. USGA Green Section Record 41(2):1-7

Qian, Y. L., W. Bandaranayake, W. J. Parton, B. Mecham, M. A. Harivandi, and A. R. Mosier. 2003. Long-term effects of clipping and nitrogen management in turfgrass on soil organic carbon and nitrogen dynamics: The CENTURY model stimulation. *J. Environ. Qual.* 32(5):p. 1694-1700.

Schulte, E.E., C. Kaufman, and J.B. Peters. 1991 The influence of sample size and heating time on soil weight loss-on-ignition: Comm. in Soil Sci.Plant Anal. 22:159-168

SCS. 1972. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report No. 1. U.S. Dept. Agr. Soil Conservation Service, Washington, D.C. 66 pp.

Sollins. P., C. Glassman, E.A. Paul, C. Swanston, K. Lajtha, J.W. Heil, E. T. Elliot. 1999 Soil Carbon and Nitrogen: Pools and Fractions Pages 92-93 in G. P. Robertson, D. C. Colman, C.S. Bledsoe, P. Sollins, editors, Standard Soil Methods for Long-Term Ecological Research. Oxford University Press, NY 1999

Storer, D.A. 1984. A simple high sample volume ashing procedure for determining soil organic matter. Comm. in Soil Sci. and Plant Anal.. 15: 759-772.

Turgeon, A.J. 1991 Turfgrass Management. 4th Ed. Prentice Hall, Upper Saddle River, NJ.

Walkley, A., and I. A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29-37

Waddington, D. V., T. L. Zimmerman, G. J. Shoop, L. T. Kardos, and J. M. Duich. 1974. Soil modification for turfgrass areas. I. Physical properties of physically amended soils. Prog. Rept. 337. Pennsylvania State University., University Park, PA