Nitrogen and Phosphorus Leaching from Compost-Amended Lawns

Title:	Nitrogen and Phosphorus Leaching from Compost-Amended Lawns
Project Number:	2018CT317B
Start date:	3/1/2018
End Date:	2/29/2020
Funding Source	104B
Congressional District:	CT-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quality, Non Point Pollution, Nutrients
Descriptors:	None
Principal Investigators:	Karl Guillard

FINAL REPORT OF CTIWR PROJECT No. 2018CT317B
Nitrogen and Phosphorus Leaching from Compost-Amended Lawns

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February 18, 2021

Executive Summary/Abstract

Organic management of lawns has become one of the fastest growing segments of the lawncare and landscape industry. This has been spurred, in part, from concerns about synthetic fertilizers and pesticides on environmental quality and human health. Many believe that organic amendments pose little or no threat to the environment compared to synthetic chemical applications. Although N fertilization to lawns is not yet regulated in Connecticut, new laws regulate the application of fertilizer P to lawns. However, composts and other organic amendments have been exempt from the P regulations if they contain 0.67% or less phosphate (P_2O_5). This exemption has further strengthened the perception that organic fertilizers or composts are not harmful to the environment. Previous research in Connecticut has documented N leaching losses from turfgrass receiving organic fertilizers, and current research in Connecticut suggests that fertilizer contributes more to the embayment N loads in Long Island Sound than has been reported in previous estimates. Recent research has reported P leaching at concentrations that can cause eutrophication occurring in soils that have exceeded their P saturation index, or when extractable soil test P concentrations exceed the environmental critical level. There are little or no data about N and P leaching from compost-amended lawns. Plots of Kentucky bluegrass turf managed as lawn were established in 2017 and received varying rates of compost according to current CT NOFA Organic Land Care Standards yearly through 2020. Zero-tension soil monolith lysimeters were used to collect percolate from the plots and samples were analyzed for concentrations of NH_3-N, NO_x-N, PO_4-P and Total P. Soil samples were collected in the spring and fall and analyzed for concentrations of extractable P and potentially mineralizable N. Based on the volume of percolate collected from lysimeter, flow-weighted concentrations and mass export losses were calculated for each analyte.

The results of the study suggest that low rates of compost frequently applied to turfgrass lawns have a low risk of contributing to water quality impairment. Whereas commonly-recommended higher rates of compost to lawns may contribute to water quality impairment from leaching losses of NH_3-N, PO_4-P and Total P. Concentrations of these constituents often exceeded limits associated with water quality impairment for freshwater resources. Annual flow-weighted concentrations (FWC) of PO_4-P and Total P in 2020 were strongly correlated to routine soil test analyses of extractable P, whereas FWC of (NO_2+NO_3)-N were moderately correlated to potentially labile N as estimated with a soil amino-nitrogen test. A routine soil test for extractable P and a soil labile N test show promise in guiding compost recommendations for lawns to minimize leaching losses of P and N to shallow groundwater. Concentrations of NO_x-N did not exceed 1 mg/L when soil labile N concentrations were ≤ 170 mg/kg. Whereas PO_4-P and TP concentrations did not exceed 0.05 and 1 mg/L, respectively, when modified-Morgan extractable soil P_2O_5 concentrations were ≤ 120 lbs/ac.

Problem Statement

Soluble forms of N and P can be dissolved, and particulate forms of P can be suspended in runoff and/or leaching from the landscape, and transported to fresh surface waters where N and P act as natural regulators of primary productivity. Excess algal growth in response to elevated N and P concentrations leads to accumulation of biomass that must be oxidized aerobically, thus creating an oxygen deficit in the water column that can affect the aquatic chemistry and the biotic community when the algae die and undergo decomposition (Bostrom et al., 1988). Although P is of primary concern in freshwater, and N is of primary concern in estuarine and saltwater, N can enhance eutrophication caused by excess P in freshwater (Conley et al., 2009).

Federal and State environmental regulations have been issued to limit the amount of N and P loading to receiving waters through the Clean Water Act (CWA) and through various state and regional programs. In Connecticut, state regulations establishing Water Quality Standards (WQS) for surface and ground waters have been enacted and effective as of December 11, 2013 (https://www.epa.gov/wqs-tech/water-quality-standards-regulations-connecticut). The WQS establish use goals and set the overall policy for management of surface water and ground water quality which are necessary to protect and restore water quality. As part of the general standards indicated in the WQS regulations, Best Management Practices (BMPs) and other reasonable controls on nonpoint sources of nutrients and sediment, that would include soil tests to prevent excess N and P applications, are advocated to address a trophic state that has been altered due to excessive anthropogenic inputs, and these are deemed preferable to the use of biocides to control excess algal blooms.

Land use and the landscape in Connecticut has changed dramatically in the last 50 years. Based on the data compiled by the Center for Land Use Education and Research (CLEAR; http://clear.uconn.edu/projects/landscape/statewide.htm), turfgrass used for lawns and other recreational areas in Connecticut covers almost 250,000 acres, and surprisingly this is almost 20,000 acres more than land used for production agricultural purposes. From 1985 until recently, the turfgrass segment of Connecticut's landscape, as indicated by CLEAR, has increased by approximately 50,000 acres. As the amount of lawn area increases in Connecticut, so do the environmental concerns associated with certain lawncare practices – nutrient fertilization, pesticide applications, irrigation, etc. Current data suggest that the closer a lawn is located in proximity to a water source such as a stream, river, inlet, etc., the greater the chance of nutrient enrichment to that water source (Dostie and Vaudrey, 2015).

In response to the goals set in the Federal CWA and CT WQS, and the perceived notion that lawns are major contributors to water quality impairment, the Connecticut Legislature passed Public Act No. 12-155 in May 2012 that regulates the application of fertilizers containing P on established lawns. The Act became effective January 1, 2013. The bill requires a soil test within the previous two years indicating that P is needed before fertilizer P can be applied to lawns. However, soil amendments and compost containing 0.67% or less phosphate (P_2O_5) are not regulated under this Act, and can be applied regardless of soil test P readings. Unfortunately, this carve-out in the regulations gives the impression that compost and other organic amendments do not pose a threat to water quality.

Typical guidelines for organic management of turfgrass are to apply compost at relatively high rates in the first three years of organic management (NOFA, 2011). Current Northeast Organic Farming Association (NOFA) Standards for Organic Land Care guidelines recommend that prior to establishing turfgrass, compost should be applied to the soil surface as a 1 to 2 inch layer (approximately 3 to 6 yd^3 per $1{,}000ft^2$), then incorporated to a depth of 4 to 6 inches. A 2-inch layer is deemed appropriate for very sandy soils or soils that are low in organic matter. The guidelines further state that for more fertile soils, use less, but this statement is vague with respect to how much a reduction should be made. After the turfgrass has established, it is recommended that a topdressing or surface application of ¼ inch (0.75 yd^3) or less, be applied no more than two times per year, for no more than three years, unless a soil test shows organic matter remains below 4% and soil test P is below the "medium" category. Although these guidelines are commendable for their recognition that excess compost application could result in high soil P concentrations, they lack guidance with respect to P leaching associated with compost additions. For N, the NOFA recommendations state no more than 1 pound of soluble N per $1{,}000ft^2$ per application, with a maximum of 3 pounds of soluble N per $1{,}000ft^2$ per year; rates of N application must be further reduced after 2 years of organic management. Since most of the N in compost is associated with the organic-insoluble fractions, these recommendations could result in large total N loads to turfgrass areas, with a future potential for mineralization to soluble N forms that could be subject to leaching losses.

Surface application of compost or organic fertilizers to turfgrass can lead to rapid, excessive accumulation of N and P in the upper several centimeters of the profile. Due to the affinity of P compounds for the soil solid phase, high P concentrations have been found in soil samples at the surface (0 to 1 inch) relative to the region directly below in turfgrass amended with P organic fertilizers and composts (Soldat et al., 2009; and reviewed in Soldat and Petrovic, 2008). Recent research from our laboratory validate these findings in a Kentucky bluegrass lawn turf receiving yearly surface applications of a composted organic fertilizer (Brown et al., 2014). Our preliminary data show that soil test P concentrations increase markedly with compost rates, and that the highest concentrations were found at soil profile depths closer to the soil surface and decreased with depth. At rates consistent with current recommendations, these compost applications resulted in soil test P concentrations that were well above the agronomic critical level (the value where no further yield or biomass gains are observed in response to increasing soil test P concentrations past that level) suggested for the major field crops used for food and animal feed.

There are few published reports on N leaching in turfgrass receiving composts. In comparing N leaching losses between composts and synthetic fertilizers, higher concentrations and greater fluxes were associated with the synthetic forms (Easton and Petrovic, 2004). Most N losses in both composts and synthetic fertilizers were reported for the first 20-weeks after establishment. In Connecticut, N leaching losses from turfgrass lawns occur primarily during the late fall through early spring, and losses from organic or slow-release synthetic sources were less than synthetic fast-release formulations (Guillard and Kopp, 2004).

Recent research suggests that fertilizer contributes more to the embayment N loads in Long Island Sound than has been reported in previous estimates (Vaudrey et al., 2016). The difference was attributed to better refining of estimates for fertilizer application to lawns, parks, recreational fields, and golf courses in the more recent study. In embayment watersheds where almost all of the population is on sewers (Greenwich Cove through Pugsley Creek), and waste-water treatment facility outfall is not in the embayment, fertilizer was indicated as the major contributor to the N load (Vaudrey et al., 2016). In highly populated systems without sewer or septic (Greenwich Harbor through Pugsley Creek), N loads were largely attributed to fertilizer application.

Soil test P concentrations in excess of the soil's ability to hold P (as delineated by the soil P Saturation Index) can result in significant export of soluble P to surface water bodies (Sharpley et al., 1994). Once P is in excess in the soil, export of P from turfgrass soil can also occur (Bierman et al., 2007; Rice and Horgan, 2011). The P Saturation Index is highly correlated with the extractable soil test P concentration, and this relationship can be used to predict soluble losses of P. Based on this relationship, an environmental critical level for soil test P has been established for most agricultural soils that indicate the point where soluble P losses from the soil are most likely to occur. The environmental critical value is a threshold derived from a correlation between routine extractable soil test P and runoff or leaching P concentrations that are sufficient to produce undesirable changes when that P is transported to receiving waters. Environmental critical values typically exceed (by three to six times) the soil test P agronomic level that prevents reduction in crop yield or quality (Moody, 2011; Schendel et al., 2004). Environmental critical levels for P have been established for many of the widely-used routine agronomic cropping systems, but none exist for turfgrass; there is no established soil environmental critical level for N. This lack of an environmental critical level for N and P in turfgrass systems could contribute to excessive application of compost and organic fertilizers, and increase the chance of N and P losses to sensitive aquatic ecosystems since most lawncare and landscape practitioners are following the general CT NOFA guidelines that focus on growth and quality responses, and not on potential water quality effects.

Objectives

Objective 1: Determine if a relationship exists between soil tests (labile N and extractable P) and leaching concentrations and losses of N and P from lawn turf receiving varying rates of compost.

Objective 2: If Objective 1 relationships observed; Propose environmental critical levels of soil labile N and extractable P for compost-amended lawns to guide compost application rates.

Methods, Procedures, and Facilities

This study was conducted with zero-tension, soil-monolith lysimeters on a site that was constructed for a previous turfgrass leaching study (Mangiafico and Guillard, 2006). There are 14 soil-monolith lysimeters installed at the site, and each are connected to separate collection wells. The experiment has been initiated in June 2017, and set out as a completely random design study with seven compost rates at 0 (the control), ¼-inch, ½-inch, ¾-inch, 1-inch, 1.5-inch, and 2-inch thick applications (or approximate to 0, 0.75, 1.5, 2.25, 3, 3.75, and 4.5 yd^3 per $1000ft^2$) with two replicates. Initial compost applications at the above rates were made to the bare soil over the lysimeters in June 2017, then incorporated to a depth of 4 to 6 inches (compost average total N and P_2O_5 concentrations of 0.86 and 0.67%, respectively, and C:N ratio = 9:1). Kentucky bluegrass ('Brooklawn') was seeded over the lysimeters after compost incorporation. Beginning in spring 2018, and following CT NOFA guidelines, compost was applied twice yearly as a surface treatment through 2020. Soil samples were collected each year, spring and fall, from each lysimeter plot in locations adjacent to, but not directly over the lysimeter, to a depth of 4 inches, which is the standard sampling depth for turfgrass in our location. Percolate was collected as needed and volumes were measured and a subsample was collected and analyzed for concentrations of NO_2/NO_3-N, NH_3-N, total Kjeldahl N (TKN), PO_4-P and total Kjeldahl P (TP) (EPA methods 353.2 Rev2, 350.1, 351.2, 365.1 Rev2, and 365.4, respectively) using a Unity Scientific SmartChem 170 discrete analyzer. Due to technical issues with the discrete analyzer, data for NH_3-N or TKN concentrations are not available for 2020. Soil samples were analyzed for soil labile N using the Solvita Labile Amino N test (Woods End Laboratories, 2016), and extractable soil modified-Morgan P concentrations (McIntosh, 1969; Murphy and Riley, 1962).

Based on percolate volumes, regression analysis was used to determine the relationship of flow-weighted N and P concentrations and mass losses as a function of soil test concentrations. Environmental critical levels of soil test P concentrations were developed using the leaching response curves and the benchmark P concentrations associated with the different categories of trophic levels for Connecticut lakes as defined in the CT WQS document (Table Parameters and Defining Ranges for Trophic State of Lakes in Connecticut, p. 25).

Results

Soil Extractable P Concentrations

Modified-Morgan soil extractable P_2O_5 concentrations increased with increasing compost additions (Fig. 1). At the three highest application rates, modified-Morgan soil test extractable P approach or exceed the agronomic and environmental critical levels (40 and 80 lbs P_2O_5 per acre, respectively) that have been set for agricultural production fields.

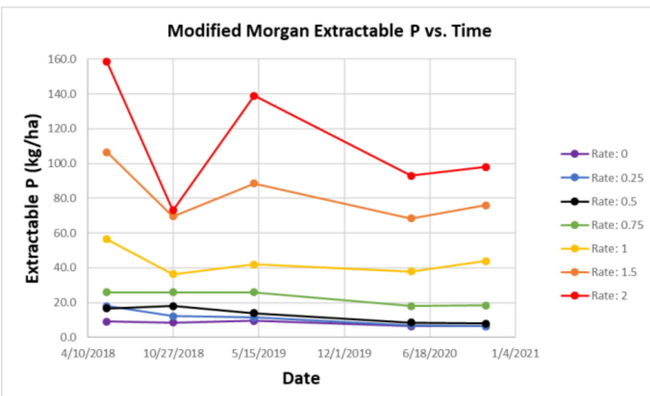


Figure 1. Modified-Morgan extractable soil phosphorus concentrations from compost-amended Kentucky bluegrass managed as a lawn from spring 2018 through fall 2020. Compost rates are inches per 1,000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

Solvita Labile Amino-Nitrogen Concentrations

Soil test values for Solvita Labile Amino-Nitrogen (SLAN) tests generally increased with increasing compost application rates (Fig. 2). Within years, concentrations were generally higher at the end of the growing season.

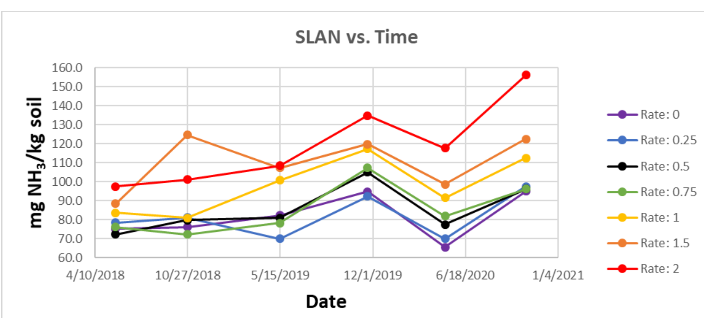


Figure 2. Solvita Labile Amino-Nitrogen soil test concentrations from compost-amended Kentucky bluegrass managed as a lawn from spring 2018 through fall 2020. Compost rates are inches per 1,000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

NH_3-N Concentrations

Leachate concentrations of NH_3-N for 2017 through 2019 are shown in Fig 3. Across compost rates, there was no consistent trend of concentrations for NH_3-N. Approximately 30% of the NH_3-N concentrations were > 0.5 mg L^{-1}. NH_3-N concentrations were generally > 0.5 mg L^{-1}, although a significant number of NH_3-N concentrations exceeded 1.0 mg L^{-1}. NH_3-N concentrations were consistently above drinking water standards of 0.25 mg L^{-1}.

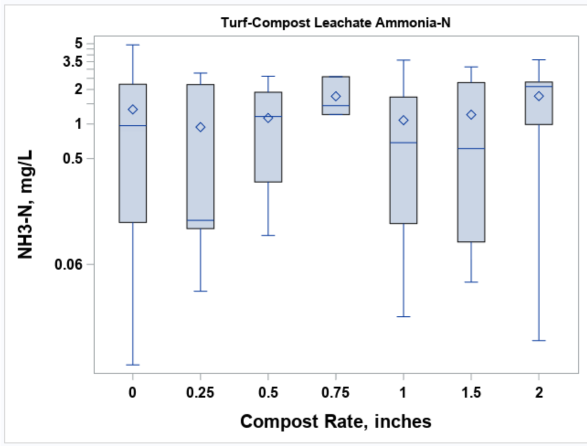


Figure 3. Concentrations of NH_3-N, fall 2017-fall 2019. Compost rates are inches per 1,000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

NO_x-N Concentrations

Leachate concentrations of Nitrite (NO_2) + nitrate (NO_3)-N from 2017 through 2020 are shown in Fig 4. Across compost rates, there was no consistent trends. Concentrations of (NO_2+NO_3)-N at times exceeded the drinking water standard of 10 mg L^{-1} NO_3-N. Typical concentrations of (NO_2+NO_3)-N were generally between 0.8 and 1.2 mg L^{-1}. Annual flow-weighted concentrations (FWC) of (NO_2+NO_3)-N were moderately correlated with SLAN values in spring (Fig. 5) and fall (Fig. 6) of 2020.

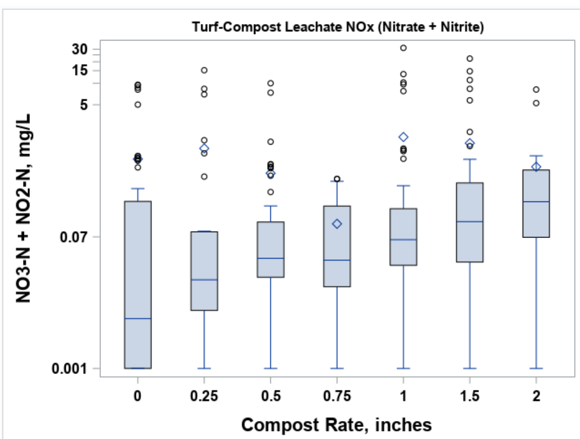


Figure 4. Concentrations of (NO_2+NO_3)-N, fall 2017-fall 2020. Compost rates are inches per 1,000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

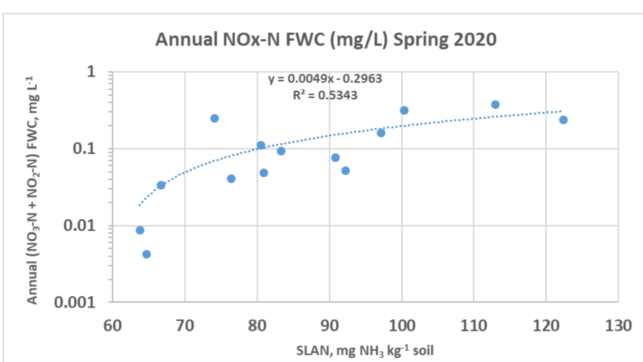


Figure 5. Relationship of annual flow-weighted concentration (FWC) of (NO_2+NO_3)-N with Solvita Soil Labile Amino-Nitrogen (SLAN) concentrations for spring 2020.

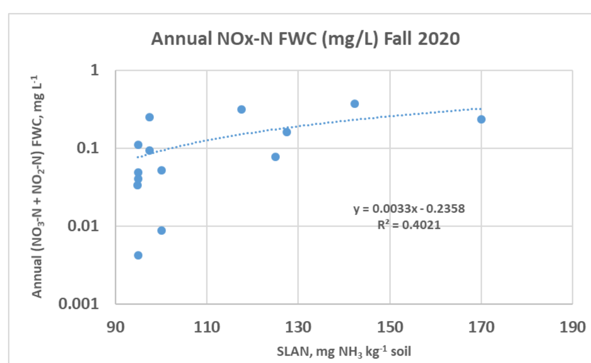


Figure 6. Relationship of annual flow-weighted concentration (FWC) of (NO_2+NO_3)-N with Solvita Soil Labile Amino-Nitrogen (SLAN) concentrations for fall 2020.

TKN Concentrations

Leachate concentrations of Total Kjeldahl Nitrogen (TKN) from 2017 through 2018 are shown in Fig 7. Across compost rates, there was no consistent trend of concentrations for TKN. Concentrations of TKN at times exceeded the defined ranges for trophic water standards of 1 mg L^{-1}, putting it in the highly eutrophic category with respect to CT freshwater lakes. TKN concentrations were generally between 0.8 to 1.2 mg L^{-1}, although some TKN concentrations exceeded 2.0 mg L^{-1}.

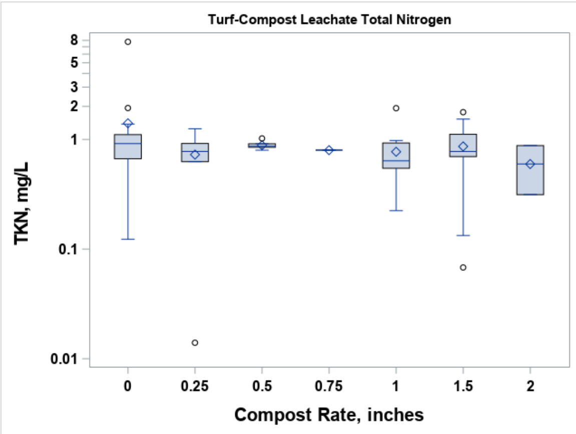


Figure 7. Concentrations of TKN, fall 2017-fall 2018. Compost rates are inches per 1000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

PO_4-P Concentrations

Leachate concentrations of ortho-phosphate (PO_4)-P, and total phosphorus (TP) from 2017 through 2020 are shown in Fig 8. Concentrations of PO_4-P were generally less than 0.05 mg L^{-1}, but several samples were between 0.1 to 0.5 mg L^{-1}. Regression analysis of PO_4-P concentrations show a significant relationship between increasing compost rate and leaching PO_4-P concentrations (Fig. 9). Concentrations of PO_4-P tended to be higher with increasing rates of compost. Annual FWC of PO_4-P had a moderate to strong correlation to Modified-Morgan extractable P soil test values for spring (Fig. 10) and fall (Fig. 11) for 2020.

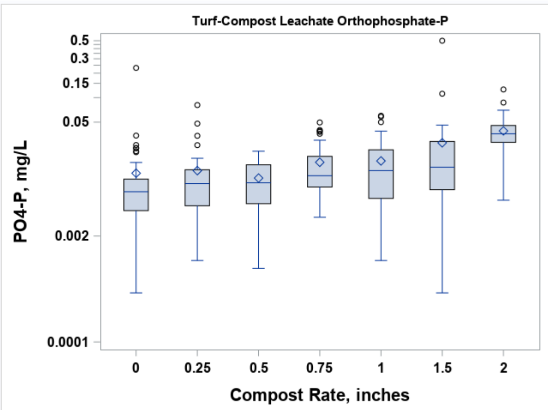


Figure 8. Concentrations of PO_4-P, fall 2017-fall 2020. Compost rates are inches per 1000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

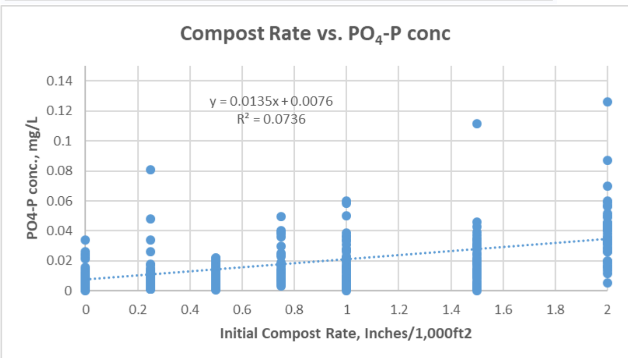


Figure 9. Relationship of PO_4-P leachate concentrations with yearly compost rates.

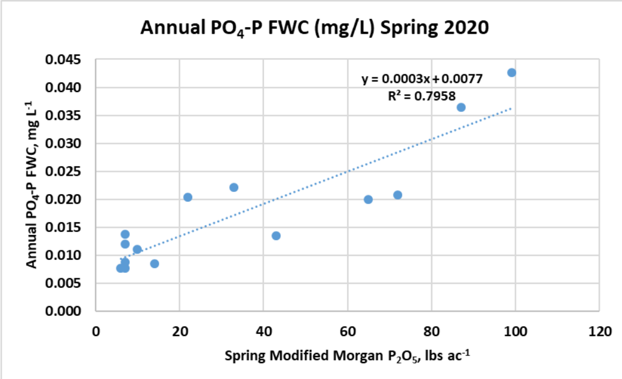


Figure 10. Relationship of annual PO_4-P flow-weighted concentrations (FWC) with Modified Morgan extractable P for spring 2020.

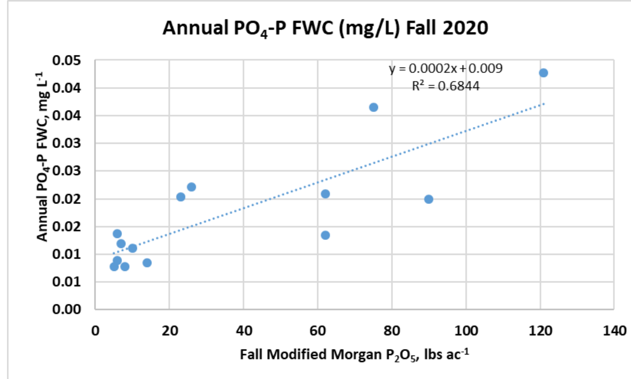


Figure 11. Relationship of annual PO_4-P flow-weighted concentrations (FWC) vs. Modified Morgan extractable P for fall 2020.

TP Concentrations

Leachate concentrations of TP from 2017 through 2020 are shown in Fig 12. Regression analysis of PO_4-P and TP concentrations show a significant relationship between increasing compost rate and leaching TP concentrations (Fig. 13). TP concentrations were generally < 1.2 mg L^{-1}, although some TP concentrations exceeded 2.0 mg L^{-1}. TP concentrations were consistently above concentrations of 0.1 mg L^{-1}. These PO_4-P concentrations would be characterized as eutrophic to highly eutrophic for CT lake water quality ranges. Concentrations of TP tended to be higher with increasing rates of compost. TP FWC were moderately correlated to Modified-Morgan extractable P soil test values for spring (Fig. 14) and fall (Fig. 15) for 2020.

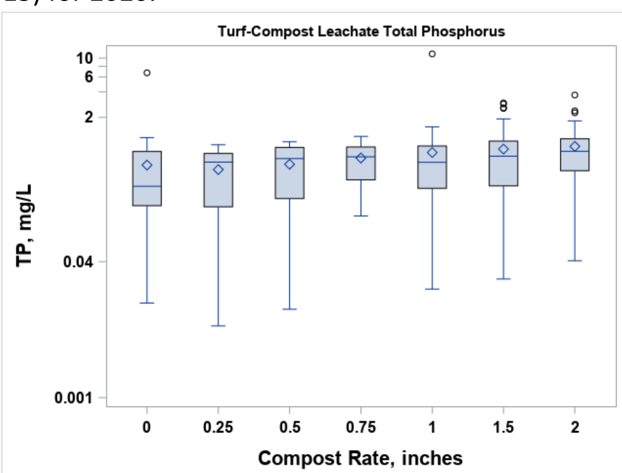


Figure 12. Concentrations of Total P (TP), fall 2017-fall 2020. Compost rates are inches per 1000ft^2 following CT NOFA Landcare recommendations (CT NOFA, 2011).

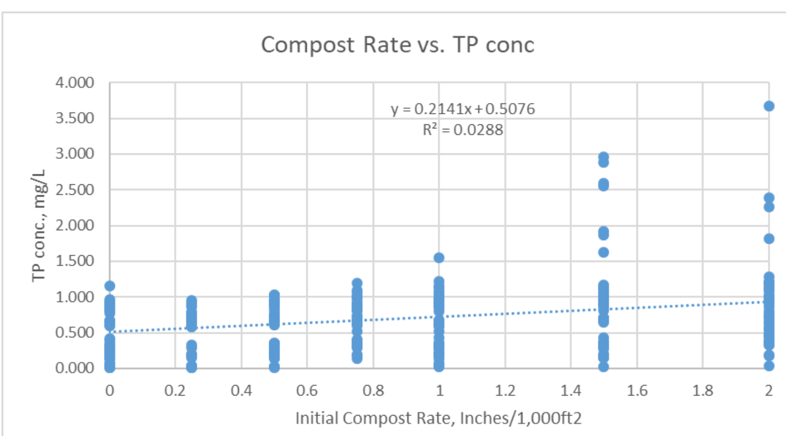
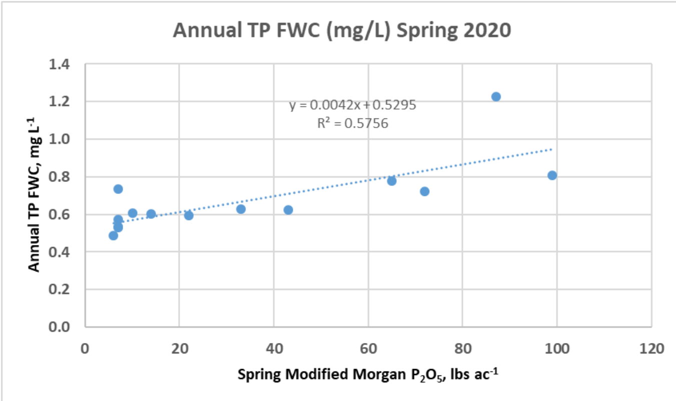


Figure 13. Relationship between total phosphorus (TP) leachate concentrations and yearly compost rates.



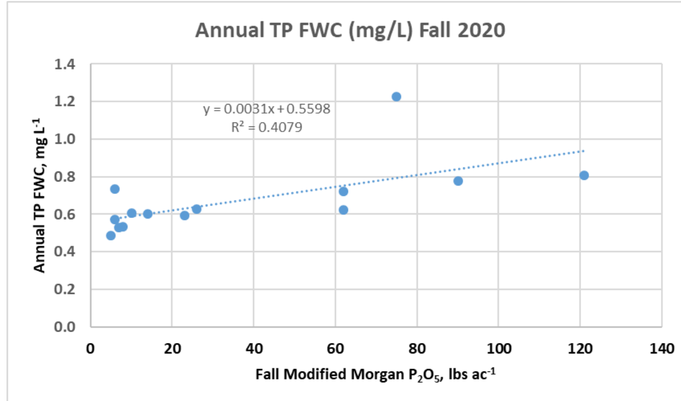


Figure 14. Relationship of annual Total P (TP) flow-weighted concentrations (FWC) with Modified Morgan extractable P for spring 2020.

Figure 15. Relationship of annual Total P (TP) flow-weighted concentrations (FWC) vs. Modified Morgan extractable P for spring 2020.

Discussion

Concentrations of the N and P constituents suggest some concern for water quality associated with a cool-season turfgrass lawn amended with compost. Mean NH_3-N concentrations were near or above 1.0 mg/L, causing concern for drinking water contamination. Similarly, several (NO_2+NO_3)-N concentrations approached or exceeded the drinking water standards of 10 mg/L, but only during the early establishment phase of the study. Once the turfgrass became established, NO_x-N concentrations were well below the maximum contaminant level for drinking water. Concentrations of PO_4-P and TP were also cause for concern. Concentrations PO_4-P were observed between 0.5 and 1 mg/L and TP concentrations at all compost rates would be categorized as contributing to highly eutrophic conditions in lakes in streams under Connecticut water quality standards for lakes.

Soil testing data suggests a moderate to strong correlation between the FWC of leachate N and P fractions and soil test values. Modified Morgan extractable P showed strong correlations with FWC of PO_4-P and TP constituents for both spring and fall 2020. Concentrations of NO_x-N were moderately correlated with soil labile N concentrations for spring and fall 2020. Spring soil test values tended to have better correlation with FWC, suggesting that spring testing may be a better predictor of leaching of N and P constituents and allow for corrective measures during the growing season. Concentrations of NO_x-N did not exceed 1 mg/L when soil labile N concentrations were ≤ 170 mg/kg. Whereas PO_4-P and TP concentrations did not exceed 0.05 and 1 mg/L, respectively, when modified-Morgan extractable soil P_2O_5 concentrations were ≤ 120 lbs/ac.

Conclusions

The results of the study suggest that low rates of compost frequently applied to turfgrass lawns have a low risk of contributing to water quality impairment. Whereas commonly-recommended higher rates of compost to lawns may contribute to water quality impairment from leaching losses of NH_3-N, PO_4-P and Total P across long-term applications. Concentrations of these constituents often exceeded limits associated with water quality impairment for freshwater resources. A routine soil test for extractable P or labile amino-nitrogen show promise in guiding compost or organic fertilizer recommendations for lawns to minimize leaching losses of P to shallow groundwater.

Acknowledgements

Funding for this project was provided by the CTIWR and the USGS. The authors thank Drs. Helton and Morris for their guidance and suggestions. The authors are especially appreciative of the assistance of the all the undergraduate student workers who helped with this project over the years. The UCONN research farm and Floriculture greenhouse staffs were invaluable to this project.

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