ABSTRACT

Title of Thesis:	HIGH QUALITY BIOSOLIDS: ASSESSMENT OF NITROGEN MINERALIZATION AND POTENTIAL FOR IMPROVING HIGHWAY SOILS
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The quality of biosolids has been improving with the upgrading of wastewater treatment plants (WWTP) as dictated by a need to meet discharge limits in receiving water bodies. Applying biosolids to agricultural soils to improve crop production has been practiced for decades. Biosolids industry has been exploring ways to use biosolids in specific situations such as highway roadside soils to improve soil properties. Roadside soils are known to be compacted and contaminated due to vehicular traffic. The objective of this study was to investigate the efficacy of high quality biosolids to improve soil physical and chemical properties. It was concluded that bloom is more effective than fertilizer at improving roadside soil physical properties and bloom, sand, and sawdust mixture is more effective than pure-bloom. Bloom can significantly increase soil organic-N mineralization. Further study will be

needed for the effect of deer compost and the mineralization rate of Orgro amended soil.

HIGH QUALITY BIOSOLIDS: ASSESSMENT OF NITROGEN MINERALIZATION AND POTENTIAL FOR IMPROVING HIGHWAY SOILS

by

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Dedication

To my parents, friends for your endless support, encouragement and inspiration throughout my study.

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Chapter 1: Introduction

Biosolids are sewage sludge that has been treated to reduce pathogen levels and remove odor. They are rich in organic matter (OM) and nutrients such as nitrogen (N) and phosphorus (P). When applied to soils as amendments, biosolids can significantly increase soil organic matter (SOM) and thus improve soil physical properties such as hydraulic conductivity, bulk density, aggregate stability, and water infiltration (Khaleel et al., 1981; Lindsay and Logan, 1998; Zebarth et al., 1999; Neilsen et al., 2003; Tsadilas et al., 2005; Lu et al., 2012). Biosolids application can also improve soil fertility and crop yields (Neilsen et al., 2003; Speir et al., 2004; Mantovi et al., 2005; Samaras et al., 2008). The usage of biosolids within the United States and Maryland state has been summarized in table 1 and table 2.

Table 1 Biosolids Usage in the United States

Biosolids use	Percentage
Agriculture	36 %
MSW Landfill	28 %
Class A Products	11 %
Incineration	15 %
Reclamation and Forestry	2 %
Monofill	2 %
Other	6 %

Table 2 Biosolids Usage in Maryland State

Biosolids usa	Percentage
Agriculture and land application	6 %
Digested	7 %
Marginal land application	4 %
Storage	6 %
Hauled out of state	60 %
Hauled to another WWTP	15 %

Most studies have applied biosolids in agricultural or forest soil. However, less research has been done on the effect of biosolids on poor-quality soil, such as soils on the highway roadside. Tsadilas et al. (2005) reported that biosolids application on clay loam soil in significantly increased SOM content and improved soil physical conditions. Neilsen et al. (2003) found that surface application of biosolids and mulch significantly decreased soil bulk density and increased soil wet aggregate stability and infiltration rate of sandy soils in an apple orchard. Lindsay and Logan (1996) observed that anaerobically digested sewage sludge significantly decreased soil bulk density and increased porosity, moisture retention, and aggregate stability in a silt loam soil.

The efficacy of high-quality biosolids to improve physical properties of the roadside soil has not been well studied. Sewage sludge was observed to be an effective in improving OM, Kjeldahl N, and vegetation cover, and decrease heavy metal content when applied to restore road embankment soils (Ferrer et al., 2011). Oña and Osorio (2006) found that the growth, survival, and germination rate of the carrying plants on a highway embankment were improved, and soil erosion was reduced when sewage sludge was applied. There are also several studies where sewage sludge was used as the fill material for road embankments. For instance, Disfani et al (2013) found that the bio-degradation and settlement rate of biosolids is affected by the pH when used to fill the road embankment (Disfani et al., 2013), Arulrajah et al (2013) concluded that biosolids were not suitable to be used as fill material due to potential pollution to water bodies and lack of bearing capacity (Arulrajah et al., 2013), and Pengcheng et al. (2008) concluded that the application of sewage sludge on a highway embankment improved soil available nutrients, OM, and water content, and further reduced soil bulk density, soil erosion, and enhanced ryegrass growth (Pengcheng et al., 2008). This study was conducted in China where the soil condition and covering vegetation species can be very different from those of the United States.

The objective of this study was to evaluate the efficacy of high-quality biosolids to improve soil fertility and physical properties of a simulated road soil. The soil properties studied were soil hydraulic conductivity at saturation, soil bulk density, SOM content, and N and P content in the soil and plants. Turfgrass was used as the cover vegetation, and high-quality biosolids produced at Washington DC Water's wastewater treatment plant, trade-named Bloom, were applied.

Biosolids are being produced on a large scale at wastewater treatment plants (WWTP). Different WWTPs use different treatments or treatment combinations. Rigby et al. (2016) summarized six types of biosolids with different treatments or combinations that lead to different types of chemical reactions and various degree of biodegradation (Rigby et al., 2016). These treatments essentially result in different N availability in final products. The six types of biosolids are raw unstabilized sludge, digested (aerobically or anaerobically) biosolids, lime-treated biosolids (alkaline stabilized), thermally dried biosolids, composted biosolids, and air-dried biosolids. Bloom is a thermal hydrolysis pre-treated (THP) and anaerobically digested (AD) exceptional-quality (EQ) biosolids. During the production of Bloom, DC water has incorporated the CAMBI© system, which is an energy-efficient thermal hydrolysis pretreatment process that uses high-temperature and pressure to break down the cell structure of the various components in the sludge, including the microbes. Since Bloom is a new product, little research has been done on the nutrient analysis and N availability. Wang et al. (2018) did a full-scale study of Bloom and compared it with DC Water's previous product. They concluded that Bloom had lower metal concentration and fecal coliform density and higher N and P content than the biosolids that they are previously producing (Wang et al., 2018). Armstrong et al. (2017) compared Bloom with the previous product but focused on triclosan, triclocarban, and their transformation products. They concluded that Bloom had lower triclocarban but higher triclosan and several other transformation products than the previous product. However, the impact of the CAMBI© system and combined anaerobic digestion on N transformation are not studied and well understood.

When used as soil amendments, one important characteristic to understand about biosolids is N mineralization process, which is the release of N due to the degradation of OM. Existing studies commonly use field or laboratory incubation to quantify the N mineralization rate or potential. Silva-Leal et al. (2013) compared the N mineralization rate of thermally dried biosolids, alkaline treated biosolids, and untreated dehydrated biosolids. They concluded that thermally dried biosolids and alkaline treated biosolids had significantly higher N mineralization rate than the untreated biosolids (Silva-Leal et al., 2013). Rouch et al. (2011) studied the N mineralization of two types of biosolids: air-dried biosolids and stockpiled biosolids, through a 70-day in-laboratory incubation in a controlled environment. They found that air-dried biosolids provided more nitrate-N than stockpiled biosolids and can substantially release N for a long period of time, and consequently can replace inorganic fertilizer in agricultural production (Rouch et al., 2011). Hseu and Huang (2005) conducted a 48-week incubation of three tropical soils amended with anaerobic biosolids or aerobic biosolids, and reported the N mineralization rate for both biosolids using the first-order kinetics. They found that the nitrogen mineralized matches the first order kinetics calculated by the nonlinear least square equation. However, the mineralization process of THP-AD treated biosolids, such as Bloom, is less studied.

The current study measured the N content of Bloom at each stage of the production to understand how each treatment affects the N transformations. An N mineralization study of the fresh Bloom and cured Bloom was conducted to determine the N mineralization rate and potential and plant available N (PAN) of the Bloom. The field study of the effect of applying Bloom on the simulated roadside soil on soil fertility and physical properties, together with the laboratory study of the N mineralization, will increase our understanding of the efficacy of biosolids used for land application, define parameters for estimating PAN as part of the nutrient management process, and provide valuable insights on the effects of the biosolids application.

1.1 Goals and Objectives

The objectives of this study are as follows:

1) Evaluate the efficacy of high-quality biosolids to improve soil fertility and physical properties of simulated roadside soil, focusing on soil hydraulic conductivity at saturation, soil bulk density, SOM content, and N and P content in soil and plants.

2) Investigate the effect of biosolids treatments in the series of thermal hydrolysis pretreatment, anaerobic digestion, and belt pressing on different forms of N, such as total N, organic N, NH^3/NH^{4+}-N, and nitrate/nitrite-N, in the Bloom.

3) Determine the N mineralization potential by conducting a short-period in-lab incubation of biosolids and soil mixtures.

Chapter 2: Literature Review

2.1 Biosolids Application to Improve Soil Physical Properties and Fertility

Tsadilas et al. (2005) conducted a 3-year field study where they applied biosolids to a clay loam soil in central Greece. They used cotton as the carrying plant and used different application rate of 0, 10, 30, and 50 Mg ha^{-1} yr^{-1}. At the end of the experiment, they compared the SOM content, bulk density, soil water retention and field capacity of soils amended with different application rate, also cotton yield was compared. Their findings included: biosolids application increased cotton yield and changed soil physical properties; soil physical properties such as field capacity, infiltration rate, and soil aggregate stability increased; soil bulk density decreased; and the change in soil physical properties was a consequence of increasing SOM (Tsadilas et al., 2005).

Zebarth et al. (1999) conducted a 3-4-year field experiment with six types of biosolids produced from different facilities to an infertile sandy soil. Only three biosolids were applied in the fourth year and all six biosolids were applied for 3 years. The application rate was same for all biosolids. They compared physical and chemical properties of soils applied with different biosolids. Physical properties included soil bulk density, saturated hydraulic conductivity, and SOM content. Chemical properties included soil pH and soil cation exchange capacity (CEC). SOM content and hydraulic conductivity were higher for soils receiving biosolids than the control. Soil bulk density was higher for the control than other biosolids-treated soils. However, all of physical properties varied among different biosolids and were independent of treatment. Only two treatments resulted a higher than control CEC after three years of application. Soil pH did not significantly change compared to the control, and the difference also varied between biosolids (Zebarth et al., 1999). However, this study did not look at the difference in biosolid production procedure. The biosolids used in the study came from six facilities and they might have different wastewater treatment. Also, the study did not provide a detailed analysis of each biosolids. If the researchers had a better understanding of the biosolids, the variation in effects on physical and chemical effect can be potentially explained.

Neilsen et al. (2003) conducted a 7-year study in an orchard where the soil is a gravelly sandy loam with low OM and low water-holding capacity. They compared the efficacy of seven practices including glyphosate application, which is a standard practice in commercial orchard maintenance, unincorporated biosolids application, shredded paper application, alfalfa mulch application, polypropylene application, composted biosolids application, and AD and thermophilically digested biosolids application. At the end of study, they concluded that all treatments improved soil physical properties compared with the standard practice, soils with shredded paper treatment and composted biosolids treatment had higher wet aggregate stability and lower bulk density compared to the standard practice, AD-thermophilic biosolids and alfalfa application increased infiltration rate where shredded paper treatment and polypropylene treatment did not change the infiltration rate significantly compared to the standard, all biosolids treatments significantly increased P compared to other treatments, alfalfa application had higher K rate, and shredded paper application had higher Ca rate, all biosolids treatments increased potential nutrient retention due to the increase of CEC (Neilsen et al., 2003). This study had better observation on the effects of long-term biosolids application (7-year) than previous studies. However, the treatments in this study were not consistent and comparison of the treatment effects among different treatments were not very clear.

Lindsay and Logan (1998) conducted a field study where AD sewage sludge was applied to a Miamian silt loam. They compared the effect of different application rate, ranging from zero to 300 Mg/ha, on soil several physical properties. This study has important enlightenment and reference significance to the proposed study because many soil sampling and measuring methods were derived from this study. For instance, they measured the soil bulk density using the core method of Blake and Hartge (1986) and the hydraulic conductivity using the constant head method of Klute and Dirksen (1986). The core method for measuring soil bulk density is to obtain a fixed volume of soil using a steel cylinder and a Bjkelkamp core sampler, and the mass of the soil can be obtained after drying to a constant weight at 105º, and the bulk density can be obtained by dividing the mass of soil by the volume (Blake and Hartge, 1986). The constant head method for hydraulic conductivity is to measure the water flux of a sealed soil core under constant pressure that is controlled by the head height (Klute et al., 1986). Lindsay and Logan (1998) concluded that all soil physical properties including bulk density, saturated hydraulic conductivity, particle density, porosity, moisture retention, aggregate stability, shrinkage, liquid and plastic limits were changed due to the application of sewage sludge. The change in physical property is linear to the application rate except aggregate stability and diameter. Organic carbon was increased linearly to the application rate as well. It was also inferred that observed soil physical property changes were due to the added SOM (Lindsay and Logan, 1998).

Samaras et al. (2008) conducted a 4-year field study to observe the fertilizing effect of an aerobically digested and dewatered biosolids, in comparison to inorganic fertilizer. They used cotton as the carrying plant. Biosolids and fertilizer were applied for four consecutive years. Biosolids application rate were 10, 30, and 50 Mg dry solids ha^{-1} yr^{-1} for four years and fertilizer was applied at one rate to provide 160 kg NH^{4+}-N ha^{-1} yr^{-1}. Soils at two depth range (0–25 cm and 25–50 cm) were analyzed for pH, P, K, OM, and total N. Soil physical properties include bulk density, gravimetric water content, and infiltration rate were measured for 0–25 cm soils. It was concluded that sewage sludge application significantly improved SOM, soil physical properties, and nutrient content except K. The highest application rate could potentially cause surface and ground water contamination. The lower application rate was sufficient to improve soils conditions compared to the fertilizer.

Montovi et al. (2005) conducted a 12-year study in Italy using an AD, belt-pressed, and wheat straw composted biosolids on a silty-loam soil. Biosolids were applied at 7.5 Mg dry solids ha^{-1} yr^{-1} for the first two years and at 5 Mg dry solids ha^{-1} yr^{-1} for the remainder of 10 years. Biosolids application was compared with the inorganic fertilizer that was applied at the rate of 180, 120, and 300 kg N ha^{-1} yr^{-1}. This study mainly focused on the crop yield of wheat, maize and sugar beet. It was concluded that the lowest application rate for biosolids is sufficient to obtain relative yield that was resulted from highest inorganic fertilizer rate. And the lowest biosolids application in sufficient for crop growth. Higher than 5 Mg dry matter ha^{-1} yr^{-1}

application could result in wheat lodging and poor-quality grain. The application of biosolids increased SOM and soil N and reduced alkalinity.

Ferrer et al. (2011) experimented the effect of sewage sludge applied on highway embankment by evaluating the vegetation cover and several soil agronomic parameters such as fulvic acids, humic acids, carbon nitrogen ratio (C/N), organic carbon, total Kjeldahl nitrogen (TKN), and pH. They concluded that sewage sludge treated soils had higher levels of humic extract, OC, and organic material, and that the vegetation cover on the road embankment was significantly improved by the addition of sewage sludge.

Ona and Osorio (2006) conducted an experiment in Spain, which was similar to the proposed study. They applied sewage sludge on the road embankment with silt loam that was low in agricultural characteristics and no vegetation. Local plant species were selected as the carrying plants and were planted using hydroseeding method. They also considered the effect of slope. At the end of the study, they compared the growing condition of different species resulting from different sewage sludge application rate and side slope. They found that only different plant species had different growing condition, side slope and application rate did not affect the plant growth.

2.2 Biosolids Making and Effects of Biosolids Treatments on Nitrogen Availability

Wang et al. (2018) did a full-scale study where they measured the chemical properties, pathogen level, and heavy metal content of Bloom. The study focused on comparing properties between Class A biosolids (Bloom) and Class B biosolids (the previous product produced at DC Water). The study also did a temporal analysis using Bloom produced at the startup stage and the full operational stage. Properties being compared included total and volatile solids content, fecal coliform content, trace metal content, and nutrient content. The nutrient study mainly focused on nitrate/nitrite-N, Ammonia N (NH^3-N), total Kjeldahl N (TKN), and total phosphorus (TP). The previous biosolids product from DC Water was lime stabilized (Alkaline treated biosolids (ATB)) and it was gravity thickened. It was classified as class B biosolids. Bloom is the current product and it is thermal hydrolysis pretreated (THP), anaerobically digested (AD), and mechanically dewatered (belt pressing). Bloom is classified as class A biosolids.

Methods used in the study to determine the N content were adapted from EPA methods 1685, 1690, 1688. Briefly, an automated QuAAtro™ nutrient analyzer (Seal Analytical, QuAAtro39, Mequon, WI) was used for the final analysis for all types of N. For nitrate and nitrite, 3 g samples were mixed in deionized water to dissolve nitrate/nitrite—N before analysis. For NH^3/NH^{4+}-N, 5 g samples were mixed with a 0.025 M anhydrous sodium tetraborate ($Na_2B_4O_7$) buffer solution (25 mL) and water (250 mL). The pH was adjusted to 9.5. The mixed solution was distilled at 135°C to generate NH^3 gas. The NH^3 gas was captured using 0.04 N sulfuric acid (50 mL). And the titrated solution was sent to the analyzer for the final analysis. For TKN, each sample (1 g) was mixed with digestion acid solution (a mixture of mercuric-sulfate, potassium sulfate (K_2SO_4), and sulfuric acid) firstly in the digestion tube, and was digested in a block heater (Foss, Digestor 2508 autorack, China) at different temperatures. The final solution was then sent to the analyzer (U.S. EPA, 2001a; b; c).

Because this study will focus on the N, only N analysis results are discussed here. For Bloom, TKN was reported to be 52000 ± 13300 (n = 43) mg / kg (5.20 ± 1.33 % dry weight) and NH^3-N was reported to be 7860 ± 1350 (n = 43) mg / kg (0.786 ± 0.135% dry weight). For class B biosolids, TKN was reported to be 3.97 ± 0.623 % dry weight and NH^3-N was reported to be 0.131 ± 0.0366 % dry weight. Bloom had higher TKN and NH^3-N then class B biosolids. The nitrate/nitrite-N was below the detectable level (0.09 mg / kg) and was not reported. The reason for this result was concluded as the thermal hydrolysis process encouraged the breakage of organic matter and more organic N was released, also alkaline treatment increased the pH which resulted in more NH^{4+}-N being transformed into NH^3, which was released into the air (Wang et al., 2018).

Rigby et al. (2016) conducted a meta-analysis on the N availability of different types of biosolids. Biosolids type included raw unstabilized sludge, digested (aerobically or anaerobically) biosolids, lime-treated biosolids (alkaline stabilized), thermally dried biosolids, composted biosolids, and air-dried biosolids. They concluded on the total N mean concentration, mineralizable N, and plant available nitrogen (PAN). They concluded that the mean concentration of total N ranged from 1.5% to 7.5% based on dry basis, of which mineralizable N was 34% to 47% and declined with extend biological stabilization, and the PAN was consistent for major biosolids. Also, mineralizable N varied significantly among climatic regions even for similar types (Rigby et al., 2016).

Lu et al. (2012) reviewed the land application of biosolids and focused on the beneficial or disadvantageous effects of biosolids application, but also concluded on the effect of biosolids treatment on nutrient availability. It was concluded that the both the source of wastewater and wastewater treatment affect the nutrient values of biosolids. Commonly, digestion and composting will decrease the OM due to decomposition and ammonia-N due to volatilization, and increase P, K, and trace metal concentration. Lime stabilization reduce N, P, and metal concentration, but increase Ca concentration due to the addition of lime. Also, aerobically digested biosolids had significantly higher mineralizable N then anaerobically digested biosolids (Lu et al., 2012).

2.3 Mineralization Studies of Soils Amended with Biosolids

Gilmour et. al. (2003) conducted a comprehensive study to examine the N mineralization rate and OM decomposition rate of biosolids. The study involved 37 different types of biosolids that were collected from WWTPs across the country. They conducted a laboratory study, a field study, and a computer simulation study. The laboratory study aimed to quantify the net mineralization rate of soils amended with biosolids, also the OM decomposition rate. Soils amended with biosolids were incubated for 75 days and 210 days, and the percent of OM decomposition and net N mineralization were measured. The field study examined the plant N uptake and plant total N. Plant tissues and soil samples were collected before and after the application and growing season. Because this study was conducted at different locations across the country using different types of biosolids, the observed PAN was compared among biosolids types as well. At last, the computer simulation study was used to check the result from both laboratory study and the field study. The simulation used a fist-order kinetics model to estimate the C and N transfer, and it required several inputs such as monthly air temperature, precipitation, and potential evapotranspiration, also the analytical data and decomposition kinetics that were from the laboratory study. It was concluded that the PAN formed during the biosolids application was affected by many factors such as biosolids decomposition, weather, and biosolids inorganic and organic content(Gilmour et al., 2003). This study is helpful to the proposed study because it provided many useful information on the incubation conditions such as moisture region, incubation duration, and the measurement of inorganic nitrogen.

The lab incubation focused on the study of biosolids organic matter decomposition and N mineralization. Total solids, total carbon, total N, C:N ratio, organic N, NH^3-N, and NO^3-N were analyzed and reported for different biosolids. It was concluded that the N mineralization is linear to the OM decomposition. Inorganic N were extracted using 1 M KCl. NH^{4+}-N was determined using the salicylate method and nitrate/nitrite-N was determined using the cadmium reduction method. Methods were originally from Mulvaney (1996). Total C and N were determined using a LECO (St. Joseph, MI) Total CNS 2000 elemental analyzer. And organic N was calculated using total N minus inorganic N (NH^3/ NH^{4+}-N and nitrate/nitrite-N).

The soils used in Gilmour et al (2003) incubation were collected at the depth of 0 to 10 cm at each location. Three hundred mg of biosolids were mixed with 100 g of dry soil (application rate: 300 mg per 100 g dry soil) and moisture content of the mixture was adjusted to 40 % of the field capacity. And each sample was placed in a 946 mL bottle. A base trap, which contained 10 mL 1 M NaOH, was placed in the bottle to capture carbon dioxide that was generated by organic matter decomposition.

The whole container was sealed to create an anaerobic environment. The incubation temperature was adjusted to 25°C. Base traps were collected periodically and titrated using weak acid after adding barium chloride.

Rowell et al. (2001) conducted a 391-day incubation to study the relationship between the biosolids substrate chemistry and the N mineralization and organic matter decomposition rate. They included four types of biosolids and three other types of organic materials. Four types of biosolids included 1) mesophilic, anaerobically digested, and waste activated, which means that the sewage sludge was biologically digested at 35ºC to 37ºC in anaerobic environment and was supplemented with dead microflora from the digestion tanks, 2) thermophilic (55ºC to 57 ºC) and anaerobic, but only 30% of the waste received activated sludge, 3) thermophilic, anaerobic, and not supplemented with waste-activate sludge, and 4) auto thermophilic (at 60 ºC) and aerobic, and waste-activated biosolids. The organic matter content was determined based on the loss-on-ignition method that was derived from Nelson and Sommers (1996). Carbon content was determined using a LECO carbon analyzer (LECO, St. Joseph, MI). Total N was determined using a Lachat (Milwaukee, WI) auto-analyzer after a micro-Kjeldahl acid digestion. The inorganic N was extracted and measured using the same method used in Gilmour's study. And the organic N was the total-N minus inorganic-N. The incubation duration was 391 days and was set up in three different environments including one in the greenhouse with temperature ranging from 15 to 41°C. A 250 mL plastic tub was used as the container. The container has nylon mesh at the bottom to allow water drainage and a polyethylene film on the top to allow aeration but limit evaporation. Containers were placed in seedling trays that were filled with coarse sand. Decomposer was added in by adding 10 mL of forest-extracted water. Two moisture regimes were established (dry or saturated). The interval between each sampling was not consistent. It was concluded that the relation between N mineralization and OM decomposition was weak, which is contrasting with Gilmour's study. N mineralization rate is better predicted by the amount of proteins that were determined from 13C NMR, and the content of these protein could be potentially predicted through the wastewater treatment.

Silva-Leal et al. (2013), compared the N mineralization rate of dehydrated biosolids, thermally dried biosolids, and alkaline treated biosolids. For the incubation, 280 g of soil was mixed with different rates of biosolids. The application rate was determined by PAN, which used 20 % of the organic N plus inorganic N. Soil-biosolids mixture was placed in PVC containers and the moisture was maintained at 70 % of the soil field capacity. Each experimental unit was measured periodically for different N content. For the N content, there was no significant difference between dehydrated and thermally dried biosolids. However, alkaline treated biosolids had lower N content, especially the ammoniac N. They also compared N content with results from other studies and concluded that their result on biosolids N content analysis is representative for the types of biosolids used. They reported that thermal drying significantly increased the mineralization rate whereas alkaline treatment decreased the transformation. The application dosage affects the mineralization rate in a way: higher dosage had weakened the difference caused by biosolids treatments, but the overall mineralization rate had been decreased with higher dose. Other similar studies found similar but not identical results. The authors indicated that many other factors such as soil condition and environment can affect N mineralization (Silva-Leal et al., 2013).

Rouch et al. (2001) compared the N release rate of air-dried biosolids and stockpiled biosolids through a controlled lab incubation procedure. Biosolids used in the study were both anaerobically digested under mesophilic temperature condition with one different drying treatment: one was air dried in a pan and the other one was stockpiled. Air-dried samples were dried 8 to 12 months after digestion and stockpile samples were dried for 12 to 36 months. Over the incubation, air-drying in a pan released more inorganic N. The moister regime from stockpiling released more nitrate-N whereas saturated regime showed less inorganic N remaining due to denitrification. Also, the age of biosolids affected the stability of organic N: stockpiled biosolids are more resistant to mineralization and had less inorganic N released (Rouch et al., 2011).

Soil used for incubation was the most representative tenosols in Australia. Two moisture regimes: moist and saturated were set up. Biosolids were sampled at the facility at different depths and locations and were added to soils at the ratio of 1:100 for stockpiled biosolids and 1:10 for the air-dried biosolids. Fifty grams of the biosolids-soil mixture was put in a 100 mL screw-top plastic container for the incubation. The environment was aerobic, and the temperature was maintained at 20°C. Incubation duration was 70 days and samples were measured at day 5, 10, 20, 40, and 70.

Smith and Durham (2002) studied the effect of thermal drying on the N availability for mesophilic anaerobically digested biosolids. Biosolids were produced under mesophilic anaerobic digestion. One type of biosolids was thermally dried and another was conventionally mechanically dried. Biosolids were also separated by cake (conventionally mechanically dried) or pellets (thermally dried), where cake-like solids had around 20 % dry solids and pellets solids had around 90 % dry solids. Thermally dried biosolids had lower total N content (4.3 %) and ammoniac N (5 % of TN) than mechanically dried biosolids (5.1 % TN and 23 % for ammonia N). This is due to the volatilization of ammonia. In order to compare the effects from soil, two soils with contrasting properties were used as the carrying medium for the lab incubation. The loamy sand soil had lower organic matter content and lower CEC but relatively high nitrate N than the calcareous clay soil. The application rate was 10 tonnes of dry solids per hectare area. Biosolids were thermally dried and then ground to pass 2 mm sieve before adding to the soil. Each incubation unit has 100 g of the soil-biosolids mixture. Polythene bags were used as the container and samples were left in aerobic condition and 25° C under dark condition. The incubation moisture was not specified. Before chemical analysis, samples were stored under -20°C to minimize N change (the standard technique in N transformation). Nitrate was extracted using 2 M KCl followed by colorimetric analysis.

During the incubation, nitrate N accumulated with ammonium N decreasing. Biosolids type did not differentiate the incubation pattern, however, soil type affected the N transfer significantly: clay soil had produced more nitrate than sandy soil at the beginning. It was concluded that thermal drying decreased the overall N content but increased the mineralizable N (57 % vs. 27 %, 29 % vs. 6 %) (Smith and Durham, 2002).

Chapter 3: High Quality Biosolids to Improve Soil Fertility and Physical Conditions

3.1 Overview

The field study aimed to evaluate the efficacy of Bloom and its different types of mixture to improve soil physical conditions when applied to simulated roadcut soils. Treatments for comparison included compost (deer mortality compost provided by our supporting facility) and fertilizer was used as well. An experimental site was established with 20 plots randomly assigned to 5 treatments. The effecting factors included in study have different amendments, different turfgrass mixture, and different tilling method. At the end of the study, the soil physical properties, focusing on soil hydraulic conductivity at saturation and bulk density were compared, also the nutrient analysis were compared among different factors. When compared with Bloom mixtures, pure Bloom was not the most effective amendment and the deer compost, which we did not expect to have much nutrient, outperformed all Bloom products. All treatments provided significant nutrient to turfgrass growth compared to the fertilizer control. Surprisingly, the Bloom and Sand Sawdust (BSS) mixture was the most effective one to increase soil nitrogen and phosphorus content. BSS application also significantly improved the physical condition.

3.2 Methodology

3.2.1 Study Site

Typical roadside soils have low nutrient and poor physical properties due to the construction. They can also be highly polluted by heavy metals from the vehicles. Li et al. (2016) reported that highway roadside soils have high pH, low OM, high salt level, and were highly compacted. It is important to establish a vegetative cover on roadsides to protect the soil. When establishing the vegetation cover, appropriate soil amendments are necessary due to the soil condition. According to the personal from the Maryland State Highway Administration (SHA), inorganic fertilizer is commonly used as the soil amendment. However, there are several drawbacks of using the inorganic fertilizer. For instance, inorganic fertilizer does not provide any organic substance to the soil thus does not improve soil physical properties. Also, fertilizer nutrients are readily lost by water runoff. The lost nutrients can cause further pollution if leached into water bodies. Compared to inorganic fertilizer, biosolids, as a type of organic fertilizer has several advantages such as releasing nutrients slowly, containing high OM, and containing several plant micronutrients such as B, Cl, Cu, Fe, Mn, Mo, and Zn (Lu et al., 2012).

However, it is challenging to conduct the field experiments in real roadside conditions. This study established a simulated soil to represent the roadside soil. The Maryland SHA Dayton Facility has a storage yard which has been used to store construction vehicles and materials. The soil in the yard was highly compacted with no vegetation. Soil horizons were disturbed by previous operations. Soil depth was around 25 cm. Because the soil in the SHA Dayton facility has many similarities with the actual roadside soil, it was selected as the experimental site for the field study. A soil analysis was conducted and several properties are listed in Table 1. The site location map is shown in Figure 1.

Figure 1 SHA Field Experimental Site Location

Table 3 SHA Soil Property

Soil Property	OM (%)	P (ppm)	Nitrate (ppm)	pH	C.E.C (meq/100 g)
	2.1	7	<1	8.0	19.4

Table 4 Properties of Bloom, BSS, BM, and Deer Compost

Material	Total Soilds (%)	Total N (%)	TKN (%)	Organic N (%)	Nitrate-N (%)	Ammonia-N (%)	Total P (%)
Bloom	50.87		3.58	3.35	<0.01	0.23	3.25
BSS	72.70		1.95	1.64	<0.01	0.31	2.02
BM	87.02		2.84	2.37	<0.01	0.47	1.93
Deer Compost		2.62				0.16	0.90

3.2.2 Materials and Vegetation Type

In order to compare the efficacy in improving soil conditions when establishing vegetation cover on roadside, Bloom and inorganic fertilizer were selected as two of five types of soil amendments. At the time of sampling Bloom, DC Water was producing two mixtures of Bloom and wanted to test their effects on soil. In accordance with the overall objective of our overall project, these two mixtures were selected as the materials for the proposed study. These two mixtures are Bloom mixed with mulch (BM) and Bloom mixed with sand and sawdust (BSS). The SHA produces a compost using the dead bodies of animals, mainly deer, from road accidents. Deer compost was expected to have lower nutrient and OM content than Bloom. Dead animal compost can also be applied as soil amendment in environments that have less public access, such as roadsides (Bonhotal et al., 2007). In accordance with the wishes from the SHA, deer compost was selected as the last material.

Materials were sent to the Waypoint Analytical Laboratory in Richmond, VA for analysis prior of the site establishment. Several properties of Bloom, BSS, BM, and deer compost are listed in Table 2. All analysis was reported on a dry weight basis.

The most common vegetation for highway roadside is turfgrass. However, different turfgrass mixtures can be selected for different areas. This study uses two types of turfgrass mixture. One type is provided by Maryland SHA and is used on most Maryland highway roadsides. The other type is a residential turfgrass mixture from the local vendor. The composition of and germination rate of each turfgrass mixture are listed in table 3.

3.2.3 Application Rate

The application rate followed the suggestion from EPA's Process Design Manual (1995). For soil reclamation purposes, organic materials should be applied at five times the plant available nitrogen (PAN) of 14.65 g / m^2 (3 lbs N / 1000 ft^2) (US EPA, 2018; Alvarez-Campos and Evanylo, 2019). To be specific, for reclamation projects, the PAN provided by each material should be five times of the recommended rate for Turf Type Tall Fescue turfgrass which is 14.65 g / m^2. At the time of calculating the application rate, there was no available resource describing the mineralization rate of Bloom and Bloom mixtures. Thus, it was assumed that 20 % of the organic-N will be mineralized contributing to the PAN (biosolids mineralization rate from Md. Agricultural Nutrient Management program). The PAN for each material, except for inorganic fertilizers, was calculated as the sum of 20 % of organic-N and inorganic-N. The inorganic fertilizer (25-0-3) had 25 % total N. It was applied to provide 14.65 g / m^2. The moisture content of each material and the area of the experimental plot were considered when calculating the application rate. The moisture content was determined by air-drying the material at 105 °C until no weight difference is observed. The area of the experimental plots will be discussed in the following section. The total amount of each material applied to each plot and side area are listed in table 4.

Table 5Composition of SHA and Residential Turfgrass Mixture

SHA Turfgrass Mixture	Residential Turfgrass Mixture
49.25% - Leonardo Tall Fescue	30.00% - AST5112 Tall Fescue
44.40% - Rockwell Tall Fescue	29.61% - Piedmont Tall Fescue
4.96% - Wild Horse Kentucky Bluegrass	29.17% - AST7003 Tall Fescue
1.39% - other crop seed, Inert Matter, and weed seed	9.90% - Bandera Kentucky Bluegrass
	1.32% - Other crop, Inert matter, and Weed Seed
Germination Rate: 90 %	Germination Rate: 85 %

Table 6 Material Moisture Content and Application Rate

Material	Moisture Content (%)	Plot (lbs)	Side Area (lbs)
Bloom	0.15	89.39	33.52
BSS	0.09	127.40	47.78
BM	0.18	95.29	35.73
Deer Compost	0.20	94.94	35.60
Fertilizer		12.3 ounce	4.6 ounce

3.2.4 Experimental Design

The study used a completely randomized experimental design which includes multiple factors. These affecting factors include material type, tilling method, and turfgrass mixture type. More specifically, five materials are Bloom, BSS, BM, deer compost, and inorganic fertilizer; two tilling methods are tilled and non-tilled; and two turfgrass mixtures are SHA turfgrass and residential turfgrass. There were 20 plots.

Each plot had an SHA turfgrass section and a residential turfgrass section. Each plot was split into a tilled and non-tilled section. The tilling section was determined randomly. Each material will have 4 replicates. SHA turfgrass was planted in the plot area and residential turfgrass was planted in the side area. The available space in the SHA yard is rectangular and is along the fence. Totally 20 plots were established in two rows, each row with 10 plots along the fence. The side area was adjacent to each plot and was in between plots. The experimental plots are depicted in figure 2[1] .

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[1] A, B, C, D, and E represents 5 types of material: Bloom, BSS, BM, Deer compost, and Fertilizer, respectively. 1 and 2 represent tilled or non-tilled tilling method, respectively.

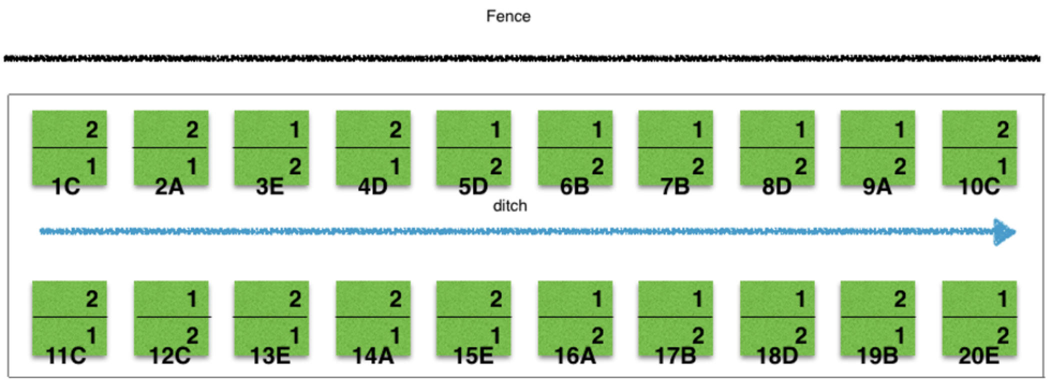


Figure 2 Experimental Plots Layout

The experimental plots were staked out using flags first. Materials were applied evenly by hand. Tilling was done using a roto-tiller, and the tillage depth was around 15 cm. After applying the material and tilling, seeding was done using a garden seeder. Seed density was controlled at 39 g / m^2 (8 lbs / 1000 f^2).

3.2.5 Sample Collection

The experiment lasted for 18 months with two growing seasons. Soils were sampled before the first growing season, after first growing season, and after the second growing season. Grass samples were collected during both first and second growing seasons. Plots set-up and material application was done in the fall and winter of 2016. The first growing season was spring 2017 and the second growing season was spring 2018. Soils were sampled in fall 2016, fall 2017, and summer 2018. Plants were sampled in summer 2017 and summer 2018. During the growing season, the site was managed every two weeks by mowing the residential turfgrass area at 3.5 inches and the SHA turfgrass area at 6 inches. The frequency followed SHA’s specifications.

For saturated hydraulic conductivity (k_{sat}) and bulk density analysis, soils must be collected in an undisturbed condition and must be in a column shape that fits into a Tempe cell in order to employ the constant head method for determining k_{sat}. The ceramic plate in the Tempe cell was replaced with a very porous sheet material (Porex^{TM}). A soil core sampler was used to extract intact and undisturbed soil samples in a brass cylinder. The soil sampler and the brass cylinder are shown in figure 3. The brass cylinder is 6 cm deep and 5.7 cm wide and can be placed in a Tempe cell apparatus (figure 3), which is utilized in the constant head method, as well as the bulk density measurement. The sampling was controlled between 2 cm and 8 cm. This can be controlled by adding a ring above the brass cylinder. The sampling scheme is shown in figure 4.

For soil chemical analysis, soils do not need to be sampled in an undisturbed cylinder but can use the same sampler for the depth requirement. Soils were stored in plastic zip lock plastic bags until analysis.

Grass samples were collected using a motorized mower with a rear collection bag. The depth was controlled at 4 inches and grass clipping tissue was collected. Grass was stored in paper bags and air dried at about 36 °C in the ENST environmental chamber for over a week.

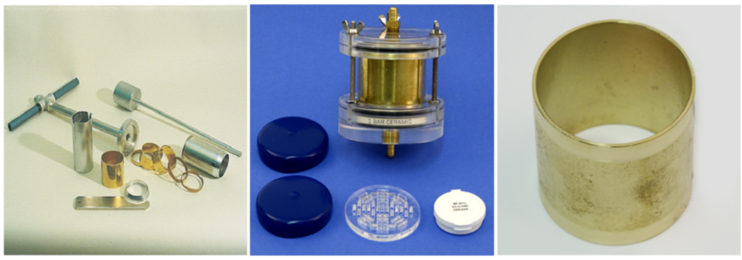


Figure 3 Soil Sampler (left), Tempe Cell (middle), and Brass Cylinder (right)

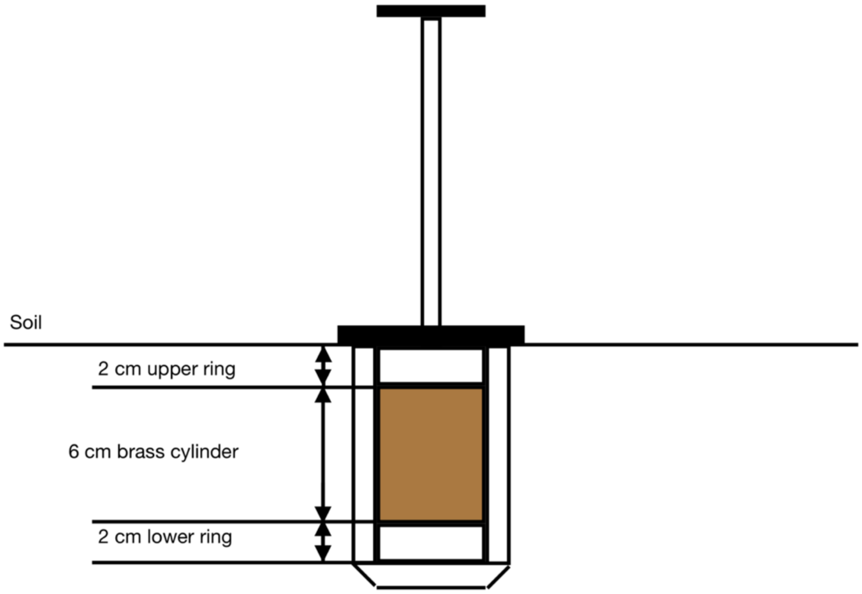


Figure 4 Soil Sampling Using the Sampler

3.2.6 Sample Analysis

Soil hydraulic conductivity was measured using the constant head method that was adapted from Klute and Dirksen (1986). The apparatus was set similar to the one shown in figure 5. The difference in hydraulic head is constant, thus the pressure difference through the soil core is constant. The flux of water in the soil core can be measured by observing the water change in the burette within a certain time period or by collecting and measuring the effluent within a certain time period. The hydraulic conductivity can then be calculated based on Darcy’s law.

Soil bulk density refers to the weight of soil per unit volume. Soil core samples used for hydraulic conductivity measurement can be used to determine the bulk density afterward. Soil core samples were dried at 105 °C until there was no change in weight. Soil weight can be obtained by measuring the brass cylinder and the core sample. The volume of the brass cylinder can be calculated given the diameter and depth of the cylinder.

Soil chemical properties were measured at the Waypoint Analytical Laboratory in Richmond, VA. The preparation was done at the ENST laboratory. Field soil samples were dried in the ENST chamber first, ground to pass 2 mm sieve, packed in plastic Ziploc bags, and then sent to the Waypoint Lab.

Soil total N and C was measured at the ENST laboratory using LECO CN628 analyzer (LECO Corporation, St. Joseph, Mich). Soils were dried at 105°C in a laboratory oven for one hour, ground to pass 0.5 mm sieve, and then put into LECO tin cups (LECO part no. 502-186-100) for analysis.

Grass samples were sent to the Delaware Agricultural Analytical laboratory for elemental analysis. Important nutrient values including N and P were reported and analyzed. In addition, the biomass of plant tissue was obtained by weighing samples before and after drying.

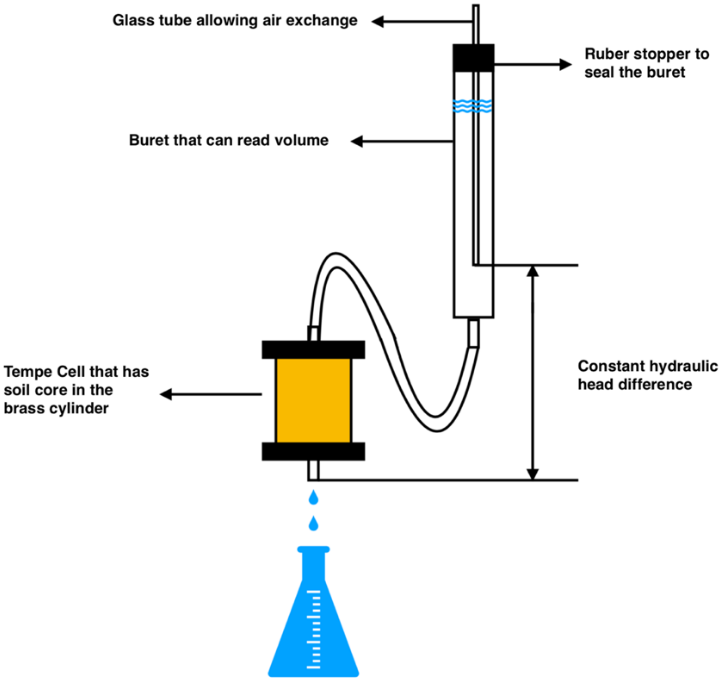


Figure 5 Constant Head Method to Measure Soil Hydraulic Conductivity at Saturation

3.3 Results

3.3.1 Soil Hydraulic Conductivity at Saturation

Soil hydraulic conductivity (k_{sat}) was measured using the constant head method and was measured before and after the growing season. The data obtained before the growing season are presented in figure 6. Only soil in the plot area was sampled and measured. It was observed that there was some variation among the locations within the experimental site. Because our plots were separated in two rows and each row had 10 plots, data points are presented in a parallel way. The average of ksat for all 20 plots was 7.12 um/s.

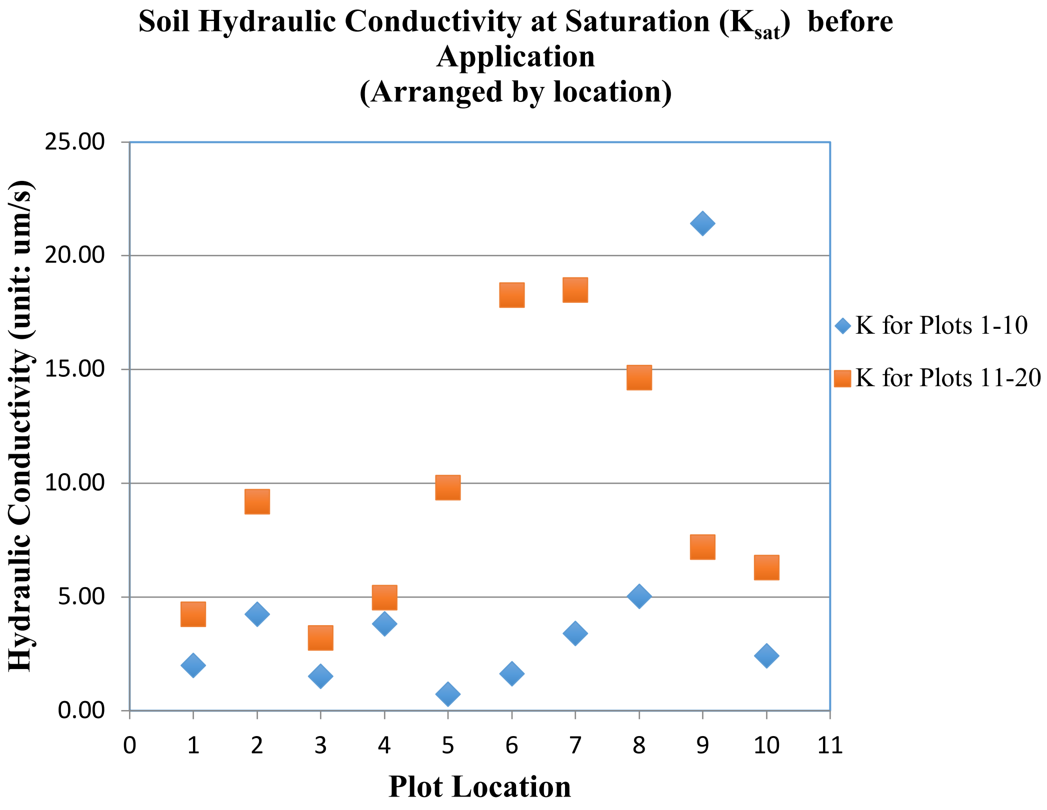


Figure 6 Soil Hydraulic Conductivity at Saturation before Material Application, Arranged by Plot Location

After the first growing season, k_{sat} significantly increased for all treatments due to both soil property improvement and root effects. After the second growing season, k_{sat} was decreased from after first growing season but still significantly higher than before the application. The difference between treatments, however, was different than expected. After first growing season, soils applied with deer compost had the highest k_{sat}. Soils treated with Bloom and mulch (BM) had the lowest ksat. Inorganic fertilizer, which theoretically did not provide any OM, outperformed BM, and less-significantly improved k_{sat} than pure Bloom and Bloom sand and sawdust (BSS) The result is shown in figure 7. Although the Deer Compost had a strong effect to improve the k_{sat} for the first growing season, Bloom resulted in the highest k_{sat} after the second growing season, indicating a better residue effect.

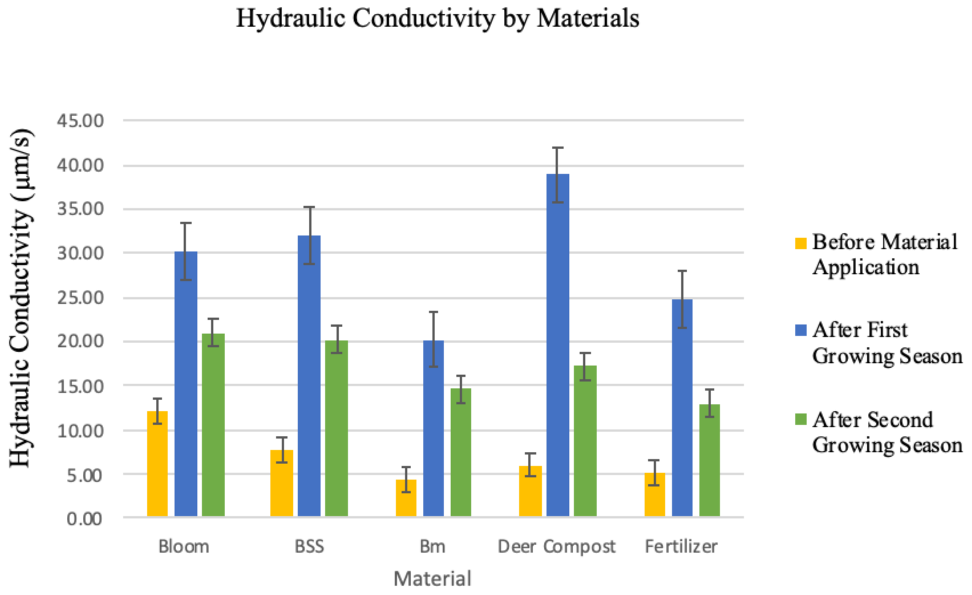


Figure 7 Soil Hydraulic Conductivity before Material Application, After First Growing Season, and After Second Growing Season, for All Treatments

3.3.2 Soil Bulk Density

Dry soil bulk density (ρ_b) was measured using the same samples for ksat measurement. After running water through the soil in the brass ring, the whole cylinder was placed on a ceramic plate and was dried in a laboratory oven at 105 °C for 24 hours. Once no weight difference was observed after drying soils for 24 hours, it was assumed that the soil was completely dry. The brass cylinder has an inner diameter of 5.3 cm and a height of 6 cm, thus the volume of the soil inside is 132 cm^3.

Bulk density (ρ_b) is typically low for high ksat soils and conversely, low ρb is common in highly compacted soils or low porosity soils. The result for ρ_b before material application matched this theory (figure 8). Similar to results for k_{sat}, ρ_b was variable in terms of plot location. The average ρ_b for 20 samples collected before the application was 1.55 g / cm^3 and this falls the range of sandy soils.

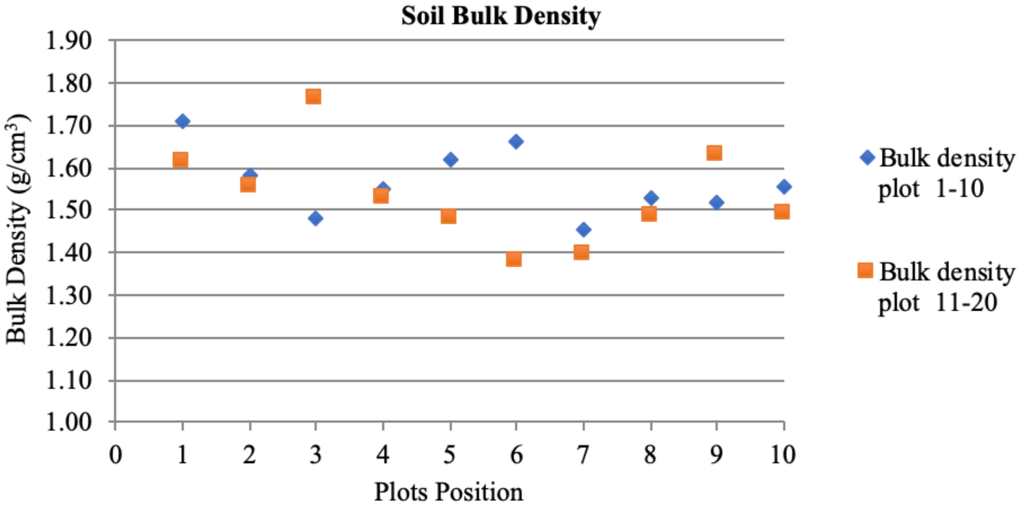


Figure 8 Soil Bulk Density before Material Application Arranged by Plots

Comparing between different treatments, soil applied with BSS had the most significant decrease in ρ_b. Bloom actually had the least effect on ρ_b. Unlike k_{sat} where a decrease was observed for all treatments after second growing season, only BSS, deer compost, and fertilizer had an insignificant increase. Soils applied with Bloom and BM kept decreasing. The overall changes in ρ_b was not as significant as the changes in hydraulic conductivity (figure 9). Bulk density results are compounded by two factors that were not accounted for in the experimental design; freeze-thaw cycles and root growth.

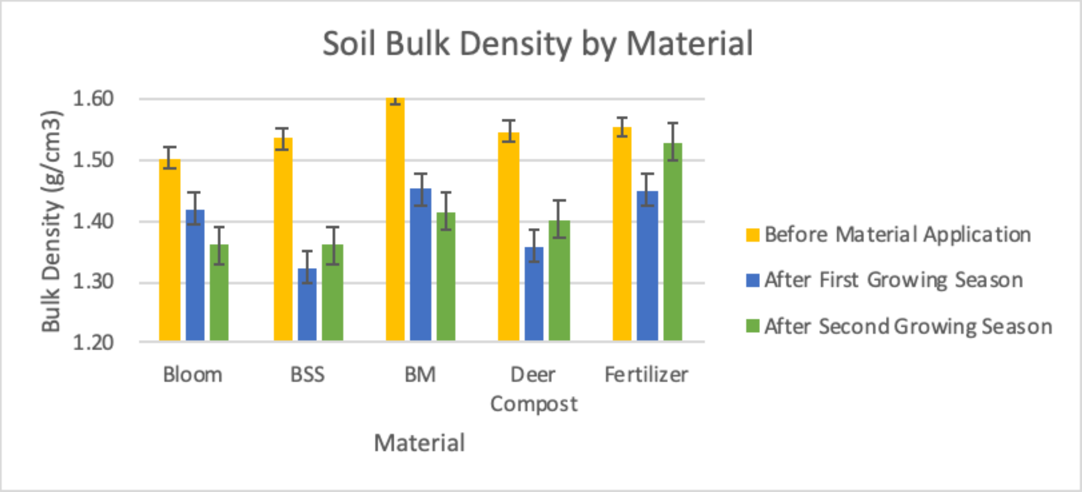


Figure 9 Soil Bulk Density before Material Application, after First Growing Season, and after Second Growing Season for All Treatments

3.3.3 Soil Total Carbon

The addition of OM from materials, except inorganic fertilizer, provided a mass of organic carbon to the soil. As expected, the total carbon in soils increased significantly for all treatments except inorganic fertilizer after the first growing season. After the second growing season, the total carbon decreased but less than the initial increase. The remaining carbon content was still significantly higher than before application. This pattern matches the hydraulic conductivity change. The increase for inorganic fertilizer could be a result of plant growth. The decrease in total carbon for all treatments could be a result of SOM decomposition. Data are presented in figure 10.

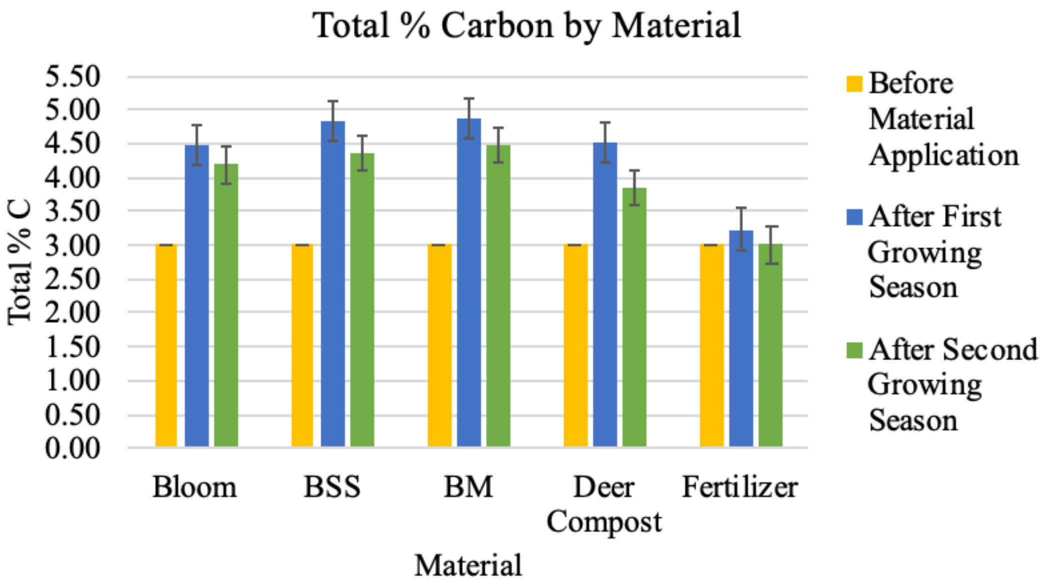


Figure 10 Total Percent Carbon for Soils before Material Application, after First Growing Season, and after Second Growing Season

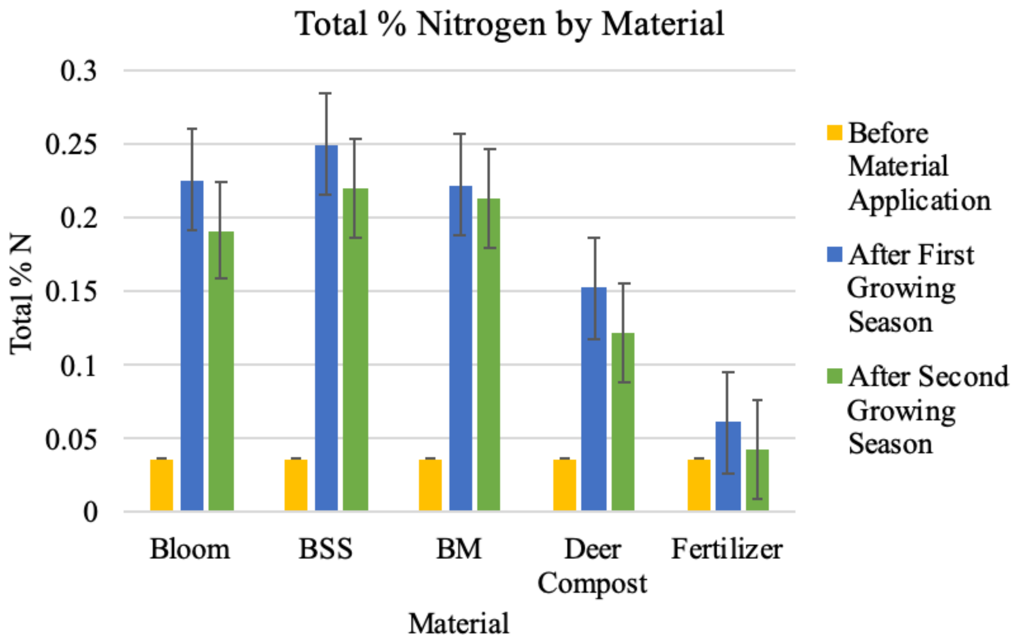


Figure 11 Total Percent Carbon for Soils before Material Application, after First Growing Season, and after Second Growing Season for All Treatments

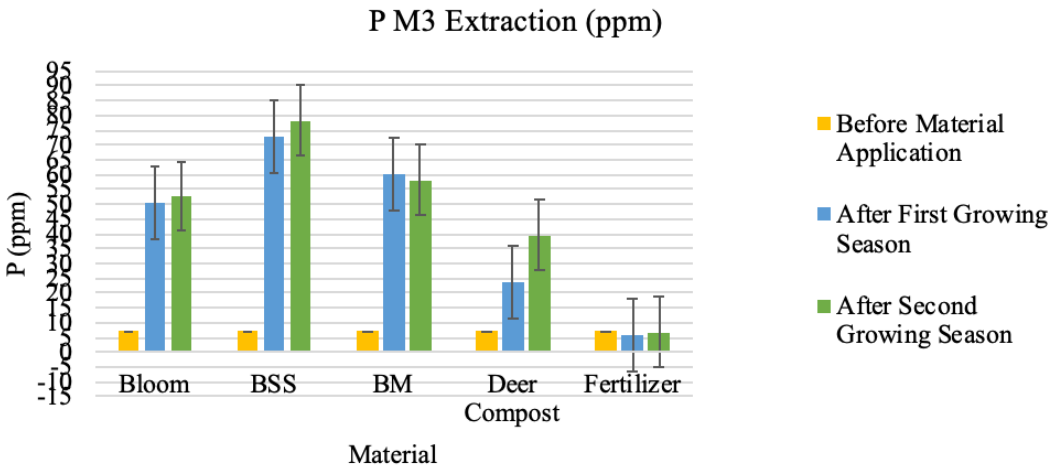


Figure 12 Soil Phosphorus before Material Application, after First Growing Season, and after Second Growing Season for All Treatments

3.3.4 Soil Total Nitrogen and Phosphorus

The change in total percent N was similar with the change in total carbon, with a significant increase after the first growing season that was followed by a less significant decrease after the second growing season. Also, similar to the total carbon change, inorganic fertilizer provided the least significant increase and residue effect compared to all other treatments. All Bloom products, including Bloom, BSS, and BM, had better performance than the deer compost and the fertilizer. Data are presented in figure 11.

Soil phosphorus was extremely high after material application and first growing season. The change between first and second growing season was not significant, in comparison to N, and this is because inorganic P tend to have less solubility in soils. The fertilizer did not provide that much of P compared to other treatments. Soils applied with BSS had the highest amount of P (figure 12).

3.3.5 Tilling Effect

The tilling effect was not as high as expected. In fact, the p value between tilling factors were not significant for all sample (table 5, 6, 7, and 8). Tilling will change the soil structure and increase soil porosity. Soil after tilling is expected to have high hydraulic conductivity and low bulk density. Especially in this field study, pretreated soil was highly compacted and poor in structure.

Table 7 Two Way ANOVA for K_{sat} after First Growing Season

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
m1	4	3078	769.4	3.376	0.014
t1	1	7	7.2	0.031	0.86
m1:t1	4	855	213.9	0.938	0.447
Residuals	68	15497	227.9		

Table 8 Two Way ANOVA for K_{sat} after Second Growing Season

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
m1	4	761.7	190.43	6.052	0.000311
t1	1	74.3	74.28	2.361	
m1:t1	4	56.4	14.1	0.448	
Residuals	69	2171	31.46		

Table 9 Two Way ANOVA for ρ_b after First Growing Season

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
m1	4	0.2046	0.05116	3.277	0.0162
t1	1	0.0443	0.04434	2.84	0.0965
m1:t1	4	0.0352	0.00881	0.564	0.6895
Residuals	68	1.0615	0.01561		

Table 10 Two Way ANOVA for ρ_b after Second Growing Season

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
m1	4	0.306	0.0765	7.534	4.27E-05
t1	1	0.0078	0.00784	0.772	0.383
m1:t1	4	0.0078	0.00483	0.476	0.753
Residuals	69	0.7006	0.01015		

3.3.6 Discussion and Conclusion

The addition of Bloom and Bloom mixtures significantly improved soil physical condition by increasing hydraulic conductivity at saturation and decreasing bulk density (Figure 7, 10, and 11). The change in physical conditions is a result of plant growth and organic matter addition, and this can be reflected from the change in total carbon. Hydraulic conductivity increased for the first growing season but decrease for the second growing season, also soil bulk density decreased and showed a trend of increasing after second growing season. This was due to the decomposition of organic matter, and it was reflected in the change of total carbon as well.

The changing pattern of total N between after first growing season and second growing season followed the pattern of total carbon, indicating that the majority N was in organic form. N mineralization happened and inorganic N is subject to leaching. However, phosphorus did not act the same way as N. Both organic P and inorganic P have low solubility and tend to stay in soils.

Comparing between different treatments, Bloom did not perform as well as expected. Since the physical changes are mainly due to SOM addition, and Bloom had the highest percent of OM, Bloom treated soil was expected to have the most physical improvement. In fact, among all the Bloom products, BSS was the best in terms of increasing soil total N and P, BM was the best in terms of changing physical conditions. Bloom products all performed better than the inorganic fertilizer in terms of soil fertility overall. However, the fertilizer treatment had better result in terms of improving soil physical conditions.

Chapter 4: Nitrogen Mineralization of Soils Amended by Bloom

4.1 Introduction

This experiment was designed to measure and compare the nitrogen (N) mineralization rate of fresh Bloom, cured Bloom, and two other organic composts. Other organic composts include a biosolids compost produced by the Baltimore City Composting Facility trade named ORGRO® and a leaf compost produced by the Maryland Environmental Service (MES), trade named Leafgro®. A 30-day laboratory incubation was conducted under a controlled environment. Incubation temperature was maintained at the room temperature (23°C); moisture content of the material was maintained at 60% of saturation. At the beginning, soil and different treatment materials were mix together. The application rate was based on the 0.7 pounds Plant Available Nitrogen per 1,000 square foot per application, which is limited by MDA regulations. When calculating the amount of material needed for every 100 g of soil, soil depth was assumed to be 15 cm (2 to 6 inches for turfgrass root depth) and the bulk density was measured to be 1.17 g / cm^3 for Clarksville soil and 1.67 g / cm^3 for SHA soil. The total N and Org-N of Bloom products were provided by DC Water. When calculating the amount of material needed for each mesocosm, 30 % mineralization rate was assumed (adapted from Alvarez-Campos and Evanylo, 2019 paper) for Bloom and Cured Bloom and 10 % mineralization rate was assumed for composts. Incubation condition was aerobic. Glass jars with plastic lids were used to establish mesocosms. The lid of the chamber was opened daily to ensure oxygen supply. Samples were analyzed for ammonium N and nitrate N periodically on day 0, 3, 6, 9, 12, 15, 18, 21, 25, and 30. At the end of the incubation, the total decrease of the organic N was calculated and the mineralizable N within the incubation period can be calculated combining the result from the control. The mineralization pattern can also be visualized by plotting the organic N content at different measuring time.

4.2 Methodology

4.2.1 Soils and Materials

This study will use two contrasting soils and four types of materials for the incubation. Two types of soils include an agricultural soil that was collected in a UMD farm and the soil from the SHA Dayton facility that was the same as the field study.

The Clarksville soil represents agricultural soil, which has good structure, high nutrient content, and rich microbial population. Clarksville soil was collected from the College of Agriculture and Natural Resources Clarksville Facility. During the sampling, surface vegetation was scooped away and only A horizon (top 25 cm) soil was collected. The bulk density of Clarksville soil was measured to be 1.17 g/cm3 using the core method (Tsadilas et al, 2005). Some soil characteristics measured from the Penn State Analytical Lab are listed here:

Soil texture:	clay loam
Soil pH:	5.6
Phosphorus:	11 ppm
Magnesium:	87 ppm
CEC:	8.9 (meq/100g)
Total N:	0.27 %
Total C:	3.32 %

SHA soil represents highway road cut soil, which has poor structure, less nutrients, and poor microbial population in comparison to agricultural soil. SHA soil was collected from the yard of the State Highway Administration Facility located in Dayton, which is the same location where the field study was conducted. During sampling, only the top 15 cm of soil was collected due to soil depth limitation. The bulk density of SHA soil was measured to be 1.67 g/cm^3 using the core method (Tsadilas et al, 2005). Some soil characteristics measured from the Penn State Analytical Lab are listed here:

Soil texture:	Loamy Sand
Soil pH:	8.0
Soil CEC:	19.4 (meg/100 g)
Phosphorus:	7 ppm
Total N:	0.7 %
Total C:	2.74 %

Soil was air dried at 36 °C in the ENST chamber first, and then sieved to pass 2 mm sieve using a mechanical shaker sieve. Soils are homogenized by sufficiently stirring and pouring between buckets before the experiment. The incubation will use four types of materials. Their description are listed in the following context.

Pure Bloom

Bloom is a THP-AD biosolids produced at the DC Water. It’s known as class A biosolids and can be applied as soil amendment to improve plant growth without restrictions. DC currently sells pure Bloom, but also cured Bloom, which was used as the second material in this experiment. Other facilities or individuals also cure Bloom following their own methods such as mixing it with compost. Other types of Bloom products are not studied in this section of the research. Pure Bloom has following characteristics (Data provided by DC Water):

Total N: 4 %
Org-N: 3.8 %
Ammonium/ammonia-N: 4600 mg / kg
Nitrate-N: < 1.0 mg / kg

Cured Bloom

Cured Bloom is the most popular on-sale Bloom product. Fresh bloom was stockpiled in an open environment and the pile was turned periodically. Curing will slow the decomposition rate and stabilize the nutrient. Compared to fresh Bloom, the ammonium/ammonia-N is less due to volatilization, the org-N is also less due to decomposition. Cured Bloom has following characteristics (Data provided by DC Water):

Total N: 3.8 %
Org-N: 3.6 %
Ammonium/ammonia-N: 33 mg / kg
Nitrate-N: 85 mg / kg

Orgro Organic Compost

ORGRO is a high organic compost produced at the Baltimore City Composting Facility. It is a mixture of Class A biosolids, wood chips, sawdust, and carbon ash. The nutrient analysis was provided by the facility as listed below:

Total N: 1 %
Org-N: 1 %

Leafgro Compost

Leafgro is compost product produced by Maryland Environmental Service (MES) using mainly grass clippings and leaves.

Total N: 2 %
Org-N: 2 %

Control: Soils without any addition was used as the control.

4.2.2 Application Rate

The application of material is aimed to provide 0.9 lbs. PAN / 1,000 ft^2 (Turner, 2014), which is equivalent to 4.4 g PAN / m^2. This application rate was chosen due to the limit from the Maryland Department of Agriculture (MDA, 2019). This limit applies to slow-release fertilizer that has 20 % or more slow-release N. The major component of Bloom is organic N (about 95 %), which is not water soluble.

The initial mineralization rate for Bloom products was assumed to be 30 % (Alvarez-Campos and Evanylo, 2019), although the result from Alvarez-Campos and Evanylo's 7 day AI incubation was significantly less (2.3 %). The mineralization rate for Orgro and Leafgro was assumed to be 10 %. The amount of Bloom and Cured Bloom needed for 100 g soil can be calculated using this equation:

$$Material(g) * (\%OrgN) * \mathbf{30}\%\ PAN + Material(g)(\%TN - \%OrgN)\ PAN = \left(\frac{\frac{100\ g}{\rho}}{D}\right) * \left(\frac{3.48\ g\ PAN}{sqare\ metter}\right)$$

The amount of Orgro and Leafgro needed for 100 g soil can be calculated using this formula:

$$Material(g) * (\%OrgN) * \mathbf{10}\%\ PAN + Material(g)(\%TN - \%OrgN)\ PAN$$

$$= \left(\frac{\frac{100\ g}{\rho}}{D}\right) * \left(\frac{3.48\ g\ PAN}{sqare\ metter}\right)$$

Clarksville soil bulk density: ρ=1.17 g/cm3
SHA soil bulk density: ρ=1.67g/cm3
Soil depth: 15 cm (turfgrass root depth 2 to 6 inches)

The amount of each material needed for 100 g soil is summarized in table 5.

Table 11 Incubation Application Rate

Soil type	Material type	Material needed (g)
Clarksville Soil	Bloom	0.15
	Cured Bloom	0.15
	Orgro	0.66
	Leafgro	0.33
SHA Soil	Bloom	0.10
	Cured Bloom	0.11
	Orgro	0.46
	Leafgro	0.23

4.2.3 Incubation Design

Mesocosms

Mesocosms were made using 7 oz glass jars. Each jar will contain a mixture of 100 g of soil and certain amount of material and were homogenized during the mixing process. Total number mesocosms was 10 (intervals) * 2 (soil types) * (5 treatments) * 3 (replicates) = 300.

Temperature

The incubation was maintained at laboratory room temperature, which was around 23 °C (Guntiñas et al., 2012).

Moisture Content

The moisture was maintained at 60 % of saturation for each mixture.

Incubation Intervals

Mesocosms were removed from the chamber for analysis at certain time intervals. These intervals are day 0, day 3, day 6, day 9, day 11, day 14, day 17, day 20, day 25, and day 30. The mineralization rate is expected to decrease with time.

4.2.4 Sample Preparation and Collection

Samples were analyzed for nitrate and ammonium. Soil nitrate and ammonium are usually analyzed using a continues flow injection analyzer such as Lachat analyzer. However, due to the unavailability of the machine, it was determined that the measurement was conducted by the Waypoint Laboratory. Since the samples from mesocosms are time sensitive, regular operating protocol will not satisfy the requirement. It was decided that the extraction procedure can be conducted at the UMD laboratory and only the measurement were done in Richmond. All the operating procedure will follow the standard procedure provide by the Waypoint Lab. To be specific, soils were dried at 105 °C overnight first, and then homogenized by grinding using a pestle and mortar. Soils were mixed with 20 mL of 1 M KCl solution and shaken rigorously for 30 minutes. The soil solution was then filtered using a Whatman #2 filter paper to get at least 10 mL filtrate. The filtrate was frozen and stored until the measurement.

4.3 Results

Samples were analyzed for nitrate and ammonium. The organic nitrogen was mineralized during the incubation. Nitrate presented an increasing trend, while ammonium showed a decreasing trend, although the ammonium for SHA soil was under the detectable limit, the trend was observed in Clarksville soils. The nitrate data for both soils are presented in figure 13 and 14. The ammonium data are presented in figure 15.

SHA soils were collected at the location that did not receive field experiment treatment. As such, the was low in fertility and poor in structure. Clarksville soils, in contrast, were from a well managed farm and was used to grow crops about 20 years ago. It was fertilized and tilled for agricultural purposes. Clarksville soils had more microbial activities than SHA soils. The increasing trend of nitrate indicates the mineralization rate and the slope of each treatment indicate the mineralization potential. It can be observed that the SHA soil has a less overall increasing in nitrate than Clarksville soil and a milder slope for all treatments. The slope for each treatment for both soils are summarized in table 5. At the same time when mineralization happens, microbes are consuming inorganic nitrogen to conduct assimilation. In the Clarksville soil, nitrogen concentration decreased for samples collected on day 9 and day 12. The rate of nitrate increases diminished and later resumed the pattern. The same pattern appeared in the Orgro treatment in SHA soils as well, but not in other treatments. Also, the decrease of ammonium (figure 15) showed a peak for Clarksville soils at around day 12 as well.

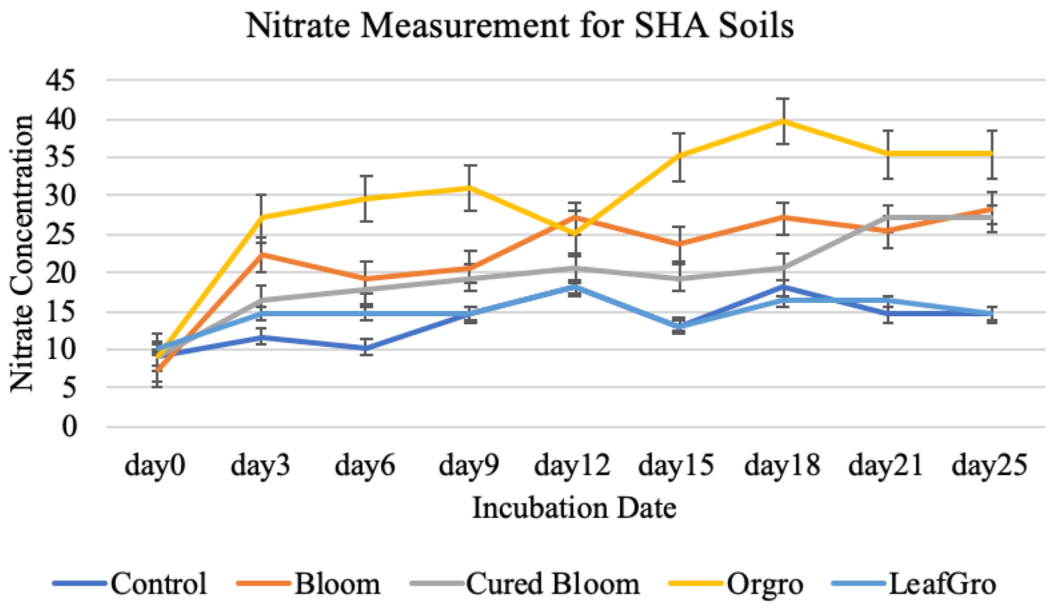


Figure 13 Nitrate Mesasurement for SHA Soil

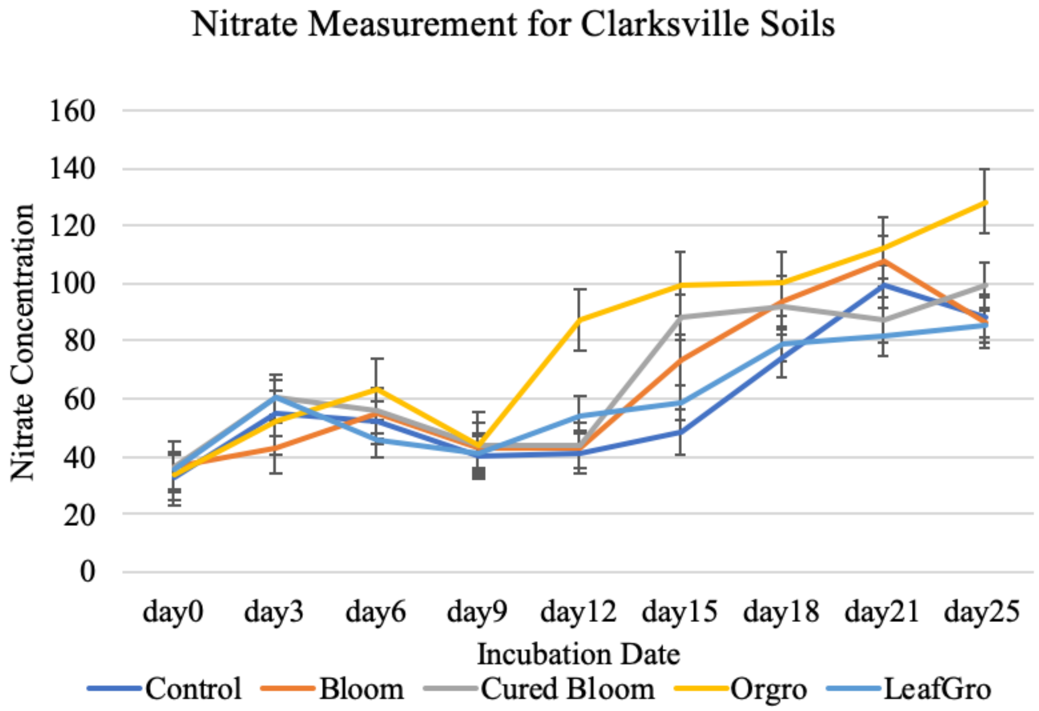


Figure 14 Nitrate Measurement for Clarksville Soil

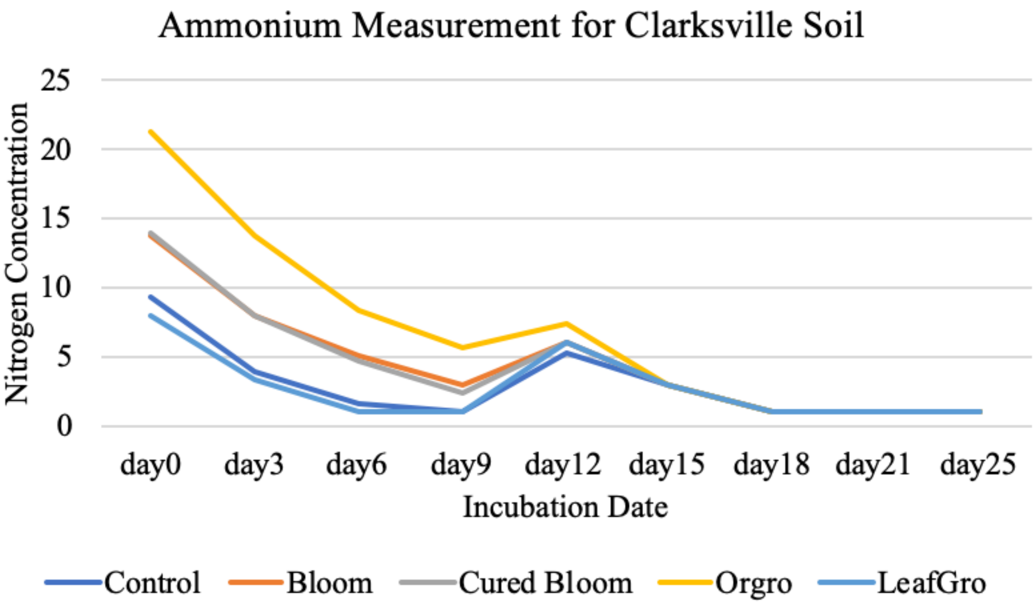


Figure 15 Ammonium Measurement for Clarksville Soil

Table 12 Nitrogen Increase Linear Trend for SHA Soil for All Treatment with the Slope Displayed

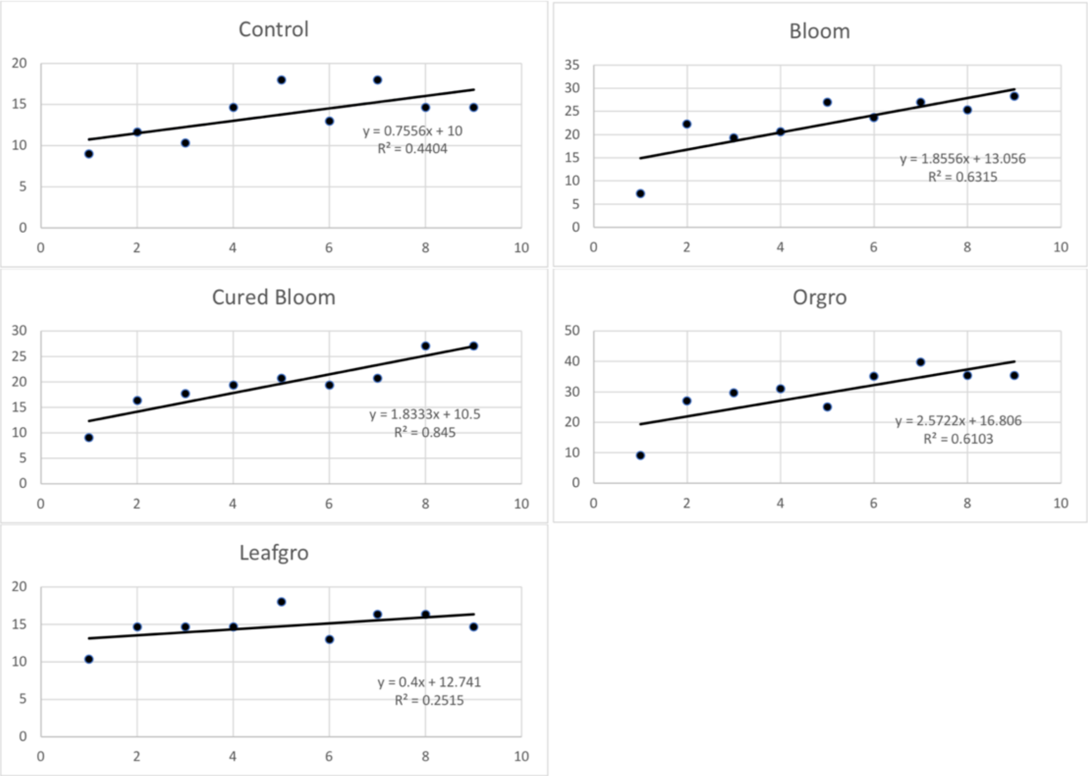
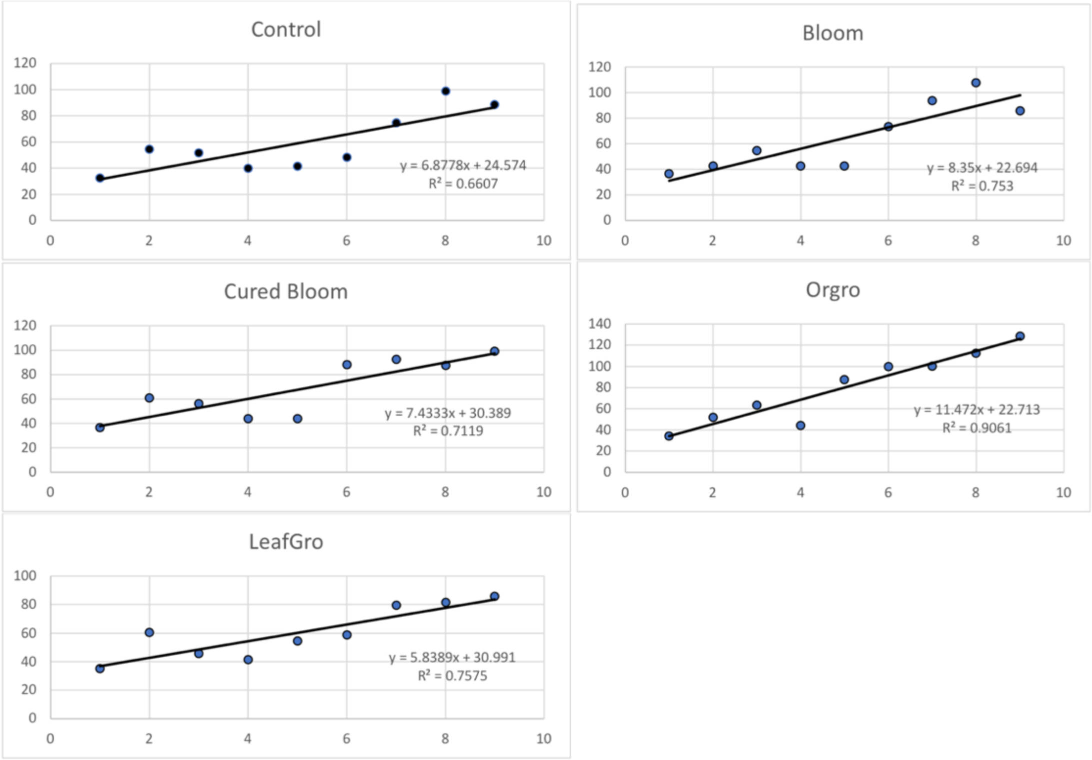


Table 13 Nitrogen Increase Linear Trend for Clarksville Soil for All Treatmenbt with the Slope Displayed



4.4 Discussion and Conclusion

Overall, soils amended with biosolids and compost presented a higher mineralization rate (slope in table 10 and 11) than the control, except for the LeafGro. The higher mineralization rate were due to the additional OM and increased microbial activities. Bloom and Cured Bloom are similar as they provide pretty much same amount of OM. Cured Bloom had slightly lower mineralization rate then Bloom for both soils. This is because, curing process will decrease decomposability of the material by stabilizing the OM. Orgro compost had the highest mineralization rate among all treatments. This is because, even though Orgro is labeled as 1 % of nitrogen, it is higher in OM (3 % to 4 %). It contains Bloom biosolids and mainly wood chips and sawdust. The mineralization rate of each material when applied to soils is strongly related to its initial organic nitrogen content. When comparing between SHA soils and Clarksville soils, Clarksville soils had a significantly higher mineralization rate. This is because the Clarksville soil represents agricultural soils that were well established and as a result there was more microbial activities in the Clarksville soil than in the SHA soil.

When bloom products are considered as soil amendments for nitrogen supply, pure bloom has a higher mineralization rate than cured bloom. Pure bloom is able to provide more readily PAN than cured bloom. However, cured bloom is still an effective organic fertilizer to provide PAN. Cured bloom had less odor and more stable organic matter. When bloom and bloom mixtures are considered for soil reclamation purposes, bloom and sand sawdust mixture is the most effective material in terms of improving soil hydraulic conductivity at saturation and soil bulk density. Bloom, sand, and sawdust is also the most effective material to provide plant nutrient such as nitrogen and phosphorus. Further study will be needed for the effect of deer compost.

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