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MARYLAND DEPARTMENT OF TRANSPORTATION
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RESEARCH REPORT

USE OF COMPOST FOR PERMANENT VEGETATION ESTABLISHMENT AND EROSION CONTROL

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UNIVERSITY OF MARYLAND

FINAL REPORT

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16. Abstract
Soil erosion management is a major environmental challenge facing highway construction. This project analyzed possible sustainable improvements to current standard procedures for final grade turfgrass establishment. Two compost types, biosolids and greenwaste, and two compost blends, 2:1 topsoil:biosolids and 2:1 topsoil:greenwaste, were compared with the standard topsoil, straw, and fertilizer in their ability to reduce soil loss and improve the rate, quality, and quantity of vegetation establishment. This research used an integrated approach of both physical and digital image analysis for both field and greenhouse studies. Vegetation establishment was measured using an image segmentation and classification technique to reduce observer bias and improve repeatability. Qualities determined for successful blanket cover included, rapid and healthy vegetative growth, reduced erosion through soil stabilization, and improved runoff retention and quality. Field grass coverage was significantly greater for topsoil at one of the sites and biosolids at the other for initial establishment, but there were no other significant differences. Greenhouse studies showed no significant coverage differences at a 20:1 slope for any media tested and both compost/topsoil blends showed no significant difference to topsoil application at the 4:1 slope. Although sediment release had greater average values for both compost/topsoil blends, only greenwaste/topsoil in the greenhouse was statistically greater than other applications. Greenhouse studies showed that topsoil application as well as topsoil/compost blends tend to produce lower concentrations of P and N than pure compost application, however the volume of runoff was greatly increased for the uncovered compost/topsoil blends. Biosolids application was the most successful at the total runoff volume reduction while greenwaste performed similarly to topsoil. Total mass of P leached after 12 in. of applied water was greatest in the greenwaste/topsoil application, while biosolids was the least. The total mass of N released was greatest in pure greenwaste and least in the biosolids/topsoil blend.

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Table of Contents

Table of Figures

TABLE OF TABLES

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1. Executive Summary

Following highway construction projects, land is left unvegetated and exposed to rainfall and soil erosion. The Maryland Department of Transportation State Highway Administration's (MDOT SHA) current practice is to cover these slopes with topsoil, fertilizer, turfgrass, and straw to establish plant growth. This practice can be costly, for both materials and transportation of materials, and may potentially leach nutrients from chemical fertilizers into stream bodies during rainfall events. Thus, there is need for a more sustainable approach to slope stabilization.

Compost has been used in some transportation projects in the United States (USEPA 2003). Several researchers found improvements to slope stability using compost and observed reductions in runoff volumes and sediment loss (Glanville et al. 2004; Faucette et al. 2005; Mukhtar et al. 2008). Compost as an additive to soil has shown an increase in soil structural stability, aggregation, and water holding capacity, adding significant benefits to the stability of post-construction slopes (Khaleel et al., 1981).

In this project, the potential benefits of compost use as a best management practice (BMP) for highway construction was investigated through two field sites and twelve greenhouse studies. These studies were designed to compare the current topsoil practice to bisolids compost and greenwaste compost application as well as 2:1 topsoil:biosolids and 2:1 topsoil:greenwaste mixtures. An integrated approach of both physical measurement and digital coverage analysis was used to compare these materials at three slopes (20:1, 4:1, and 2:1). Grass establishment was measured through a simple and reliable computer-based procedure developed to quantify coverage at both the field and greenhouse sites. First-flush storm samples were collected to measure total nitrogen (TN) and total phosphorus (TP) while mesh bags were used to collect soil runoff at both field sites. All runoff was collected in the greenhouse portion of this study and measured for TN, TP and sediments as well as N and P species.

Three observed growth periods were included in the field element of this project. The field growth studies showed few significant differences between the soil medium applications. Only biosolids (72% versus 37-60% at 90 days) at the Hanover site and topsoil (81% versus 60-69% at 87 days) at the Upper Marlboro site had significantly higher initial establishment percentages than the other applications, and none were significantly different after the first phase of growth. Grass establishment in the greenhouse focused only on the initial phase of establishment. At a 20:1 slope biosolids, topsoil, and greenwaste growth were all statistically similar (91%, 70%, and 94% establishment at 70 days). At increased slopes, 4:1 and 2:1, both biosolids and greenwaste, failed to grow above 16% establishment. Both biosolids/topsoil and greenwaste/topsoil had 31% grass establishment after 12 in. of applied water. This growth was slightly higher than topsoil's 22% establishment.

All medium applications reduced the volume of water applied to the surface. Biosolids was the most effective at volume reduction and outperformed the current MDOT SHA standard by 40-98%. The compost/topsoil mixtures produced the most runoff volume when compared to all medium applications and produced 14-25 times the volume of runoff compared to MDOT SHA standard topsoil.

Sediment transport was greatest at the Upper Marlboro site. Although not statistically significant, after 12 in. of rainfall, the cumulative mass of both greenwaste/topsoil and biosolids/topsoil blends appeared to have lost more sediment than other medium applications at both field locations, $3.4\,\frac{g}{ft^2}$ and $1.2\,\frac{g}{ft^2}$ at Hanover and $8.9\,\frac{g}{ft^2}$ and $8.8\,\frac{g}{ft^2}$ at Upper Marlboro. Greenhouse observations agreed with the field results with both compost/topsoil blends losing more sediment, but only the greenwaste/topsoil blend was statistically greater on a g/ft^2 basis. Larger storms seen in the field produced larger quantities of sediment despite medium application.

Greenhouse media studies showed that topsoil application as well as topsoil/compost blends tended to produce lower concentrations of P and N than pure compost application at 4:1 and 2:1 slopes. TP and TN values were between $1.4 - 18\,\frac{mg-P}{L}$ and $108 - 186\,\frac{mg-N}{L}$, $1.7 - 5.3\,\frac{mg-P}{L}$ and $4.8 - 25\,\frac{mg-N}{L}$ and $3.0 - 7.5\,\frac{mg-P}{L}$ and $2.4 - 47\,\frac{mg-N}{L}$ for topsoil, biosolids/topsoil, and greenwaste/topsoil, respectively, versus $1.8 - 7.2\,\frac{mg-P}{L}$ and $38 - 230\,\frac{mg-N}{L}$ and $5.8 - 7.6\,\frac{mg-P}{L}$ and $101 - 480\,\frac{mg-N}{L}$ for greenwaste and biosolids composts, respectively. The extraction data collected showed a similar trend with both composts having the most P and N, topsoil having the least, and the mixtures typically having values in between. This trend was not as evident in the field site samples. Topsoil P and N concentrations were only statistically lower when compared to biosolids and the topsoil/greenwaste mixture, and other media runoff concentrations were not statistically different to the topsoil application.

On average over the 12 in. of rainfall during greenhouse studies, the major species of P and N released were soluble reactive phosphorus (SRP) and nitrate for greenwaste (58% of TP and 77% of TN) and topsoil (62% of TP and 45% of TN); biosolids produced large percentages of SRP and ammonium (39% of TP and 52% of TN). Through the course of the study, both topsoil and biosolids released a larger percentage of TP as particulate P (from 12-61% and 16-57%, respectively), while greenwaste produced more SRP (from 38-61% of TP). Effluent TN as Organic N decreased for all medium applications with applied water (38-<1%, 73-16%, and 46-16% of TN for greenwaste, topsoil, and biosolids respectively). As more water was applied, both greenwaste and topsoil released more nitrogen as nitrate (final 97% and 68% of TN) while biosolids released more TN as ammonium (final 50% of TN).

In calculating total mass of transported nutrients after 12 in. of applied water, the total mass of P leached was greatest in the greenwaste/topsoil application with 498 mg-P while biosolids was the least with 14 mg-P. The total mass of N released was greatest in pure greenwaste with 925 mg-N and least in biosolids/topsoil with 484 mg-N.

According to both field and greenhouse observations, pure compost addition has the potential to greatly reduce the overall runoff volume, but the compost is rich in nutrients and was seen to leach both P and N at higher concentrations than the current practices. Mixing compost with topsoil produced a media with less total nutrients that produced lower leachate concentrations but had greater runoff volume.

2. Introduction

Background

As part of its commitment to environmental protection and to facilitate meeting new requirements established in Maryland House Bill (HB) 878 (now law, State Highway Administration - Compost and Compost-Based Products – Specification, 2014), the Maryland Department of Transportation State Highway Administration (MDOT SHA) continues to increase organizational knowledge on the use of novel and effective stormwater management (SWM) technologies in multi-modal transportation projects.

Following large-scale highway construction projects, miles of land are left unvegetated and exposed to rainfall. Much of this land has slopes that range from shallow 20:1 slopes to much steeper 2:1 slopes. Current MDOT SHA practices cover these slopes with topsoil, a fertilizer blend, turfgrass, and straw (*MDOT SHA Standard Specifications for Construction and Materials*, Section 705 Turfgrass Establishment) to reduce erosion through vegetation growth. The fertilizers used are chemical, ureaform with monoammonium phosphate and potassium sulfate (*MDOT SHA Standard Specifications for Construction and Materials*, Section 920.02 Soil Amendments), and the topsoil blend has low (<3%) organic matter. This practice can be costly, for both materials and transportation of materials, and potentially leach nutrients from chemical fertilizer into stream bodies during rainfall events. Thus, there is need for a more sustainable approach to slope stabilization. Through the use of compost, MDOT SHA can incorporate renewable locally sourced materials without the use of chemical fertilizers.

Compost use in transportation related state projects has been seen across the country (USEPA 2003). Several researchers found improvements to slope stability through the use of compost and observed reductions in runoff volumes and sediment loss(Glanville et al. 2004; Faucette et al. 2005; Mukhtar et al. 2008). Compost as an additive to soil has shown an increase in soil structural stability, aggregation, and water holding capacity, adding significant benefits to the stability of post-construction slopes (Khaleel, Reddy and Overcash 1981).

Research Objectives and Goals

MDOT SHA desires to evaluate the performance of select compost products in establishing permanent vegetation as part of construction site erosion prevention systems. Controlled studies will provide comparative evaluation of different compost products, mixed with top soil, in order to describe the advantages and disadvantages of the compost-based products.

In order to investigate potential benefits to compost use as a best management practice (BMP) for highway construction applications, the following objectives were designed:

- Develop a quantitative, simple, and reliable computer-based image analysis processes to measure grass coverage in both the field and greenhouse.

- Evaluate erosion protection performance of compost and compost/topsoil mixtures through image-based coverage monitoring, physical data collection, and runoff analysis.
- Provide recommendations to MDOT SHA on compost incorporation for post-construction highway slope vegetation establishment.

These objectives were met through the collection and subsequent analysis of images, stormwater runoff samples, and site-specific physical measurements taken at two field sites and four greenhouse studies.

LITERATURE REVIEW

Soil Erosion

Sediment and nutrient loss from construction sites can travel into streams and waterways affecting entire watersheds through deposition of sediments and creation of dead zones and eutrophication. The prediction and management of erosion has been the focus of many studies on an experimental, theoretical, mathematical, and observational scale for decades (Meyer 1965, Bresson L 2001, Liu and Singh 2004, Hansen, et al. 2012).

The erosion of soil from a project is a non-point source environmental pollutant; runoff produced through rainfall onto unprotected soils carries nutrients and sediments in the surface and inter-rill flows. Major elements that determine the erosive potential of a storm event are rainfall impact and overland flowing water (Hairsine P. 1991). The power of these elements to erode are controlled by soil cover, soil physical properties, and the slope steepness and length (Renard, et al. 1997). It has further been discussed that soil microtopography may also play a major role in the generation and dispersal of runoff (Liu and Singh 2004, Abrahams, Parson and Hirsch 1992). These studies suggest that irregular slopes, created by local soil minima and maxima, large particle size distributions, extensive soil coverage, and other factors can drastically affect the flow and resistance created by the soil surface. Abrahams et al. (1992) suggested that the total slope resistance is due to grain resistance, form resistance, wave resistance, and rain resistance.

Compost

The use of composted material as a means of improved vegetation establishment and runoff sediment loss has been reported in many studies (Glanville, 2004; Harrell & Miller, 2005; Curtis & Claassen, 2007; Mukhtar, McFarland, & Wagner, 2008; Hansen, Vietor, Munster, White, & Provin, 2012). Compost has been shown to beneficially modify soil properties including increased porosity and decreased bulk density, leading to an increase in soil stability, aggregation, and water holding capacity (Khaleel, Reddy, & Overcash, 1981; Mitchell, 1997; Kirchoff, Malina, & Barrett, 2003). Compost is also a recycled, renewable resource that is high in organic and inorganic nutrients.

Compost in Maryland is defined as “a stabilized organic product produced by the controlled aerobic decomposition process in such a manner that the product may be handled, stored, and applied to the land or used as a soil conditioner in an environmentally acceptable manner without adversely affecting plant growth” – (COMAR 15.18.04.01).

MDOT SHA categorizes compost by its various physical and chemical properties; stability, pH, soluble salts, moisture content, particle size and grading, and the feedstock used to create the final product (MDOT SHA spec. 920.02.05). Ultimately compost is broken down into two categories: biosolids and greenwaste compost. The first, biosolids-derived composts, come from the wastewater treatment process and are the product of composted and dewatered residual material that is combined with a bulking agent, like wood chips or peanut husks. The second, source-separated compost, is derived from any material that is not wastewater residual. This form of compost can be made from yard trimmings, grass clippings, food waste, animal manure, and more. Each of these feedstocks can contain a variety of macronutrients: carbon, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, and micronutrients: copper, zinc, iron, boron, and manganese (Diaz et al., 2007). Each feedstock is either aerobically or anaerobically broken down by bacteria, fungi and other organisms over time to create an earthy humic material rich in nutrients.

Image analysis

Accurate identification of the type and abundance of flora in an area can affect a variety of factors from slope stability and weed management practices to crop and rangeland health (Kropff, Wallinga and Lotz 1997, Society for Range Management 1995, Genet, et al. 2010). Recent advancements in digital image analysis have improved growth analysis, plant disease identification, and weed measurement (Kommedahl, 1994; Glasbey and Horgan, 1995; Gee et al. 2008). Moving from historically visually-established observations to localized site images, aerial photography, and satellite imagery creates a more updated and accurate assessment of site health and stability. These improvements directly result in specialized and site-specific weed and crop maintenance as well as site stability and ground coverage which reduces the chemical, physical, and nutrient strain placed on the environment (Felton, 1992; Wiles, 2009, Christensen et al. 2009).

Over the past few decades, photography has been used as a tool to analyze various systems (Glasbey and Horgan, 1995). This process is quickly evolving as both satellite and digital imagery become more advanced and accurate (Burgos-Artizzu, et al. 2010). Before computer-based vision analysis, many of the images captured were analyzed graphically by hand based on the Daubenmire (1959) method. Images were laid out on a grid and visual observers would create a tally of squares seen as one of the categories being analyzed. Visual techniques, like this one, were largely biased and were operator/observer-dependent (Neeser, et al. 2000, Kennedy and Addison 1987, Hatton, West and Johnson 1986). They also lacked an element of detail obtained by more computer-based analysis as many grids contained a vast number of pixels. With the advancements in image analysis, observer bias can be removed, and a more detailed representation can be achieved.

3. Methodology

Materials

Over the course of this project, three growing seasons at two field sites (Fall 2016, Spring 2017, and Fall 2017) and four greenhouse studies were completed to compare five different soil medium applications for the purpose of post construction soil erosion protection. Important aspects examined for the various media types were: initial soil nutrient loads and particle size distributions, rate and density of grass establishment, and soil and nutrient loss as a function of both water application and duration.

All surface media was seeded with an MDOT SHA turf grass mixture, from Chesapeake Valley Seed, of 95% tall fescue and 5% Kentucky bluegrass at a rate of 200 lbs/ac. Topsoil media layers received additional fertilizer, from Keymar Fertilizer Inc., at a rate of 200 lbs/ac and a ratio of 20:16:12, 83% ureaform with monoammonium phosphate and sulfate of potash; this was then covered with 4000 lbs/ac straw from Home Depot. This application is based from current MDOT SHA practices for slope stabilization and turfgrass establishment (MDOT SHA Section 705).

Topsoil was collected from The Rock Store in Hanover, MD and adheres to the current MDOT SHA Section 920.01.03 specifications. Other media used throughout this study included compost from either greenwaste or biosolids feedstock. The composts adhere to specifications in the MDOT SHA Section 920.02.05 with the greenwaste compost obtained from Leafgro® and the biosolids compost from the Aberdeen wastewater treatment facility. Both biosolids and greenwaste composted materials for this study were produced aerobically. Both field and greenhouse studies used the same five media covers: topsoil/straw/fertilizer, greenwaste, biosolids, 2:1 topsoil/greenwaste, 2:1 topsoil/biosolids.

A list of chemicals and filters used for laboratory analysis of nutrients can be found in Appendix A.

Soil Extractions

All soils were sent to AgroLab for initial soil nutrient and metals extraction analysis. They used a standard method Mehlich-3 extraction based on dry weight, without topsoil fertilization, for all medium applications. The results are: phosphorus values of 761-1180 $\frac{mg-P}{L}$, 334-565 $\frac{mg-P}{L}$, and 18-62 $\frac{mg-P}{L}$ for biosolids, greenwaste, and topsoil respectively. Media Samples also had 92-122 $\frac{mg-K}{L}$ and 32-120 $\frac{mg-Na}{L}$ for topsoil, with 573-1150 $\frac{mg-K}{L}$, >1-318 $\frac{mg-K}{L}$, 320-370 $\frac{mg-Na}{L}$, and 120-220 $\frac{mg-Na}{L}$ for biosolids and greenwaste respectively (Figure 3-1). Both composted materials had higher levels of phosphorus, potassium, and sodium than all other applications.

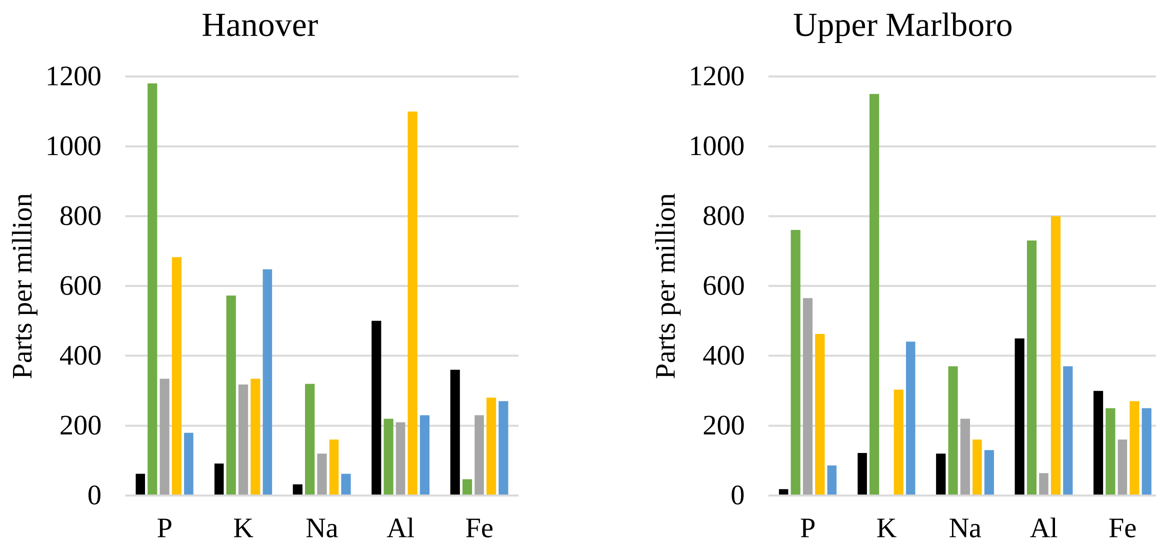
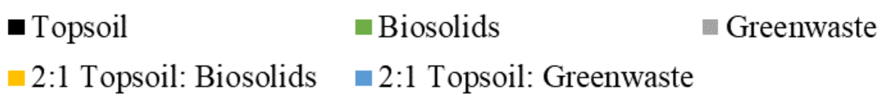


Figure 3-1: Mehlich-3 extraction results for phosphorus, potassium, sodium, aluminum, and iron at both the Hanover and Upper Marlboro locations.



Sieve Analysis

All media were dry-sieved following the ASTM D6913 method for particle-size analysis using 133-415 grams of oven dry soil (Figure 3-2). Geenwaste compost and the greenwaste/ topsoil mixture had D_{50} (coresponding to diameters at which 50% of the particles are smaller than) of 0.7 mm and 0.9 mm, respectively. D_{10} (coresponding to diameter at which 10% of the particles are smaller than) was equal to 0.2 mm for both materials. Biosolids compost had the largest particle size distribution with D_{50} and D_{10} of 2.3 mm and 0.6 mm, respectively. Both topsoil and the mixture of biosolids with topsoil had similar soil size distributions with D_{50} =1.6 mm and D_{10}=0.3 mm (Figure 3-2).

Following the USDA particle size classification, medium applications from greenwaste compost have distributions similar to a coarse/medium sand while biosolids compost ammended soils and topsoil were more similar to small gravel and very coarse sand. USDA soil textures were all similar to sandy loam, based on the AgroLab data.

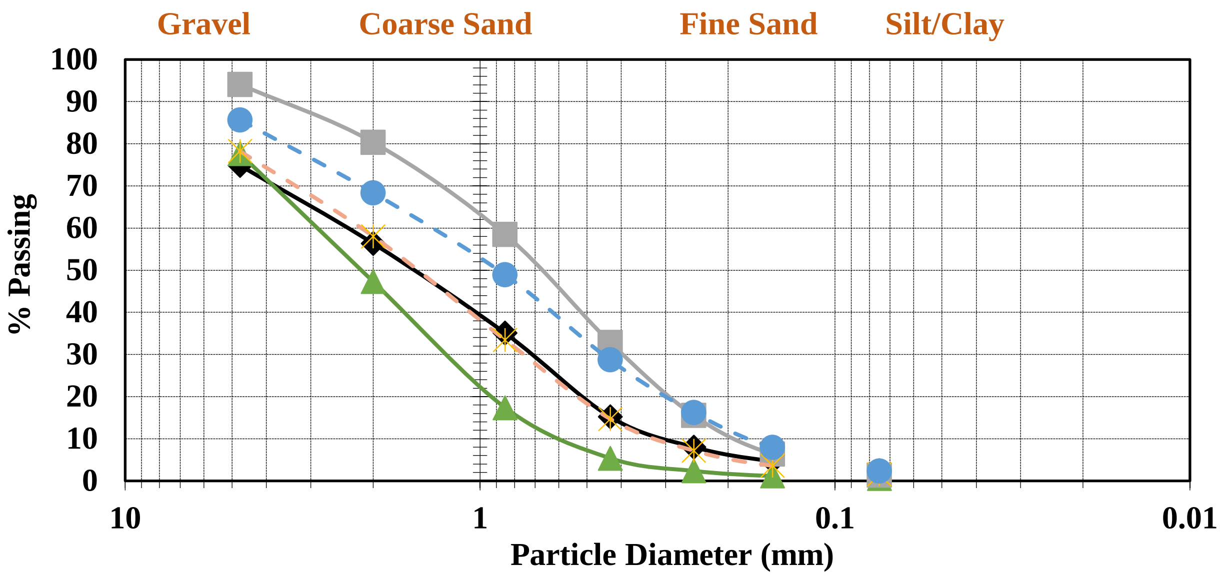


Figure 3-2: Soil particle size distribution for the materials used in this study.

Field Design

Two field sites were built in Maryland in the summer of 2016, one in Hanover, MD and the other in Upper Marlboro, MD (Figure 3-3). Sites were excavated to approximately 4 inches below the original soil height and new soil media was placed on top. Samples of soil and water runoff, grass height growth measurements, and digital image capture of grass growth were collected from these sites every two weeks or after major storm events for one full year. Both sites were built facing NE with all five media types on slopes ranging from 2:1 to 1:1. The sites were separated into fifteen different plots with 6 in. plywood dividers. All five media treatments were used in triplicate.

Compost blankets were applied at 1 in. above the surface while all other media types were loaded at 2 in. above the subsurface. Media coverage was chosen in a semi-random way along the slope to reduce the effects of neighboring plots on growth and runoff. Appendix B has a detailed description of site design and plot treatment locations.

The first site was seeded on July 26, 2016 in Hanover, MD. This site had plots built 6 ft. wide and 19 ft. long with 3 ft. gaps between every two plots. A second site was built on August 2, 2016 in Upper Marlboro, MD with plots 8 ft. wide and 40 ft. long, again 3 ft. gaps separated every two plots. Trees growing outside of the research zone produced additional shade for plots 1 and 2 at the Upper Marlboro site and plots 1, 2, 3, 4, 5, 14, and 15 at the Hanover site.

Figure 3-3: (a) Plots built at the Hanover, MD site after initial construction. (b) Upper Marlboro, MD site photo taken 87 days after slope establishment.

GREENHOUSE EXPERIMENTAL DESIGN

Following field observations, platforms were built in the University of Maryland (UMD) temperature-controlled greenhouse to monitor different variables found throughout the field study. Two 6 ft. by 6 ft. boxes were constructed with three separate sections in each. These sections are 2 ft. wide and 6 ft. long with wood dividers, covered in a granular surfaced roof leak barrier to provide surface friction to the underdrain area and prevent water movement between sections. A gutter system was built at the bottom of each section to allow the collection of all surface runoff. To prevent pooling and allow all infiltrated water to escape, a 0.5 in. gap covered in a 0.04 in. mesh was added below the gutter, along with a 2 in. drainage layer of 1:1 gravel/sand below the surface media. Media was then loaded to 2 in. above the drainage layer (Figure 3-4). All five media types tested in the field were replicated at a 4:1 slope in the greenhouse study. Additionally, the topsoil/fertilizer/straw and the two pure compost types were tested at both a 20:1 slope and a 2:1 slope.

Simulated rainfall was applied to the three-section box at two-week intervals for 12 weeks. A single 0.5 in. HH-30 W SQ Fulljet® nozzle was centered ~9 ft. above the platform to administer rain at a constant pressure of 4 psi. With this height and pressure, the simulator produced rainfall intensity of 4 in./hr. with similar diameter and terminal velocity to that of actual rainfall (Humphry, et al. 2002). The 4 psi constant pressure produced maximum uniformity over the platform but did not allow for changes in rainfall intensity. To simulate different storm events for the various slopes and medium applications, the duration of rainfall was altered. The first two storms had a duration of 15-min, the second two 30-min, and the final two were 45-min (Table 1). UMD tap water was used for these experiments due to the volume and pressure of water required. This tap water was also measured for nutrients throughout the study.

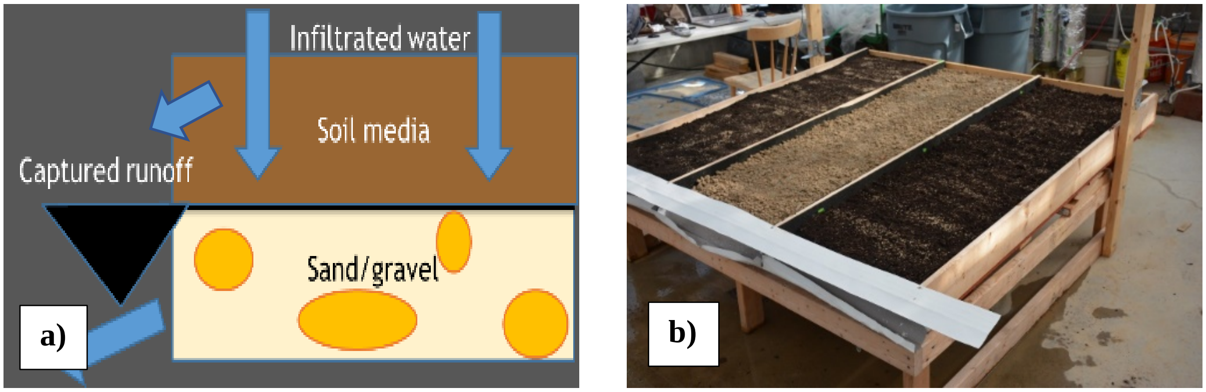


Figure 3-4: (a) Profile of the media and gravel/sand drainage layer at the bottom of the designed platform (b). Runoff is captured in the gutter system for collection and analysis with a rain guard to protect the effluent from dilution due to rainfall.

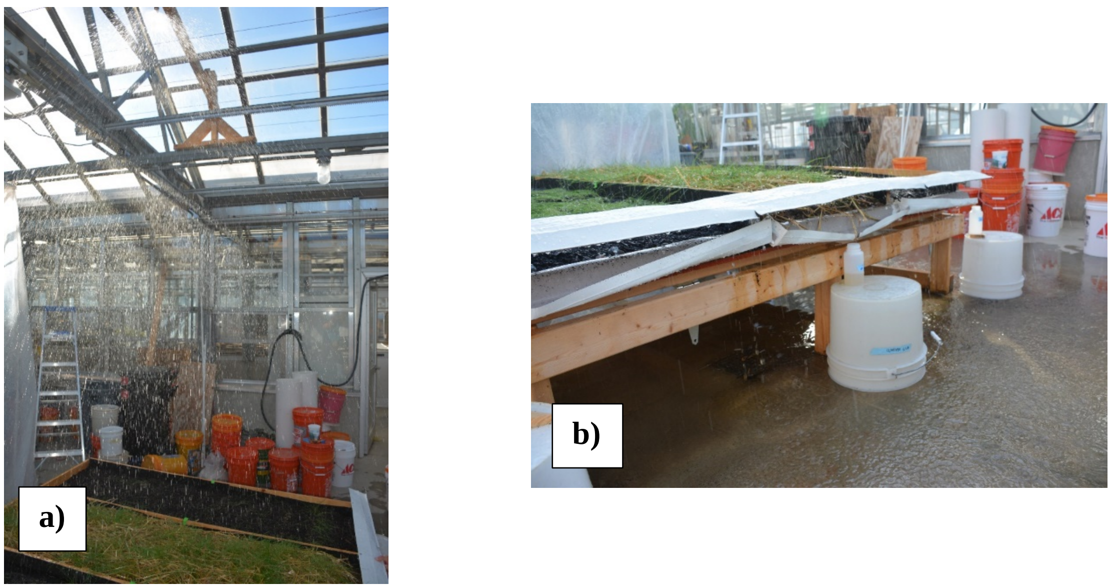


Figure 3-5: Rainfall simulator (a) producing the runoff collected in sample bottles (b).

Table 1: Synthetic stormwater application schedule and durations for greenhouse simulations.

Days since seeding	6-8	20-22	34-39	48-50	62-64	69-79
Duration	15-min	15-min	30-min	30-min	45-min	45-min
Rainfall Volume (in.)	1	1	2	2	3	3

Image Capture and Analysis

In order to properly analyze growth rates and establishment of vegetation in the field and greenhouse studies, photographs were captured approximately every 14 days. Image capture was paused during the winter months when plants were dormant and growth was at a minimum. A Nikon D7100 digital camera with an AF-S DX NIKKOR 18-140mm f/3.5-5.6G ED VR lens was used to capture all images. The auto focus feature with maximum pixel size 4000 x 6000, a hard sharpness, and normal saturation were also held constant throughout the experiments.

Before image capture, both greenhouse and field sites were divided into smaller sections for improved image quality. Field site plots were segmented into 45 in. sections and greenhouse plots were divided into two 36 in. sections along the length of the slope. This resulted in 4 images per section at the Hanover, MD site; 10 images per section at the Upper Marlboro, MD location; and 2 sections for each greenhouse plot. Field images were taken 6 ft above each plot at a 30^{o} angle while greenhouse images were taken directly above the center of the section at a height of 4 ft (Figure 3-6).

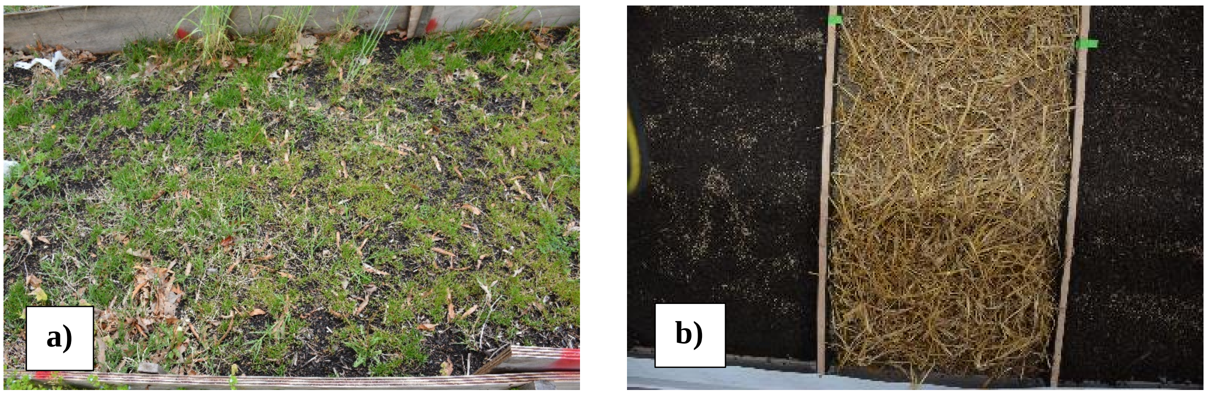


Figure 3-6: (a) Captured images from the field site and (b) the greenhouse.

After image capture, the photos were cropped to include only the region of interest (ROI) and exclude elements of the image that were not necessary in the coverage classification process or repeated in multiple images. The resulting images, Figure 3-7, represent a section of slope that corresponds to approximately 3.6 x 6 ft and 2 x 3 ft for the Hanover and greenhouse setup respectively.

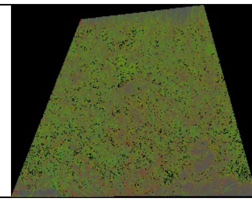
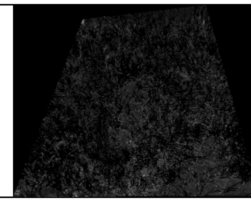
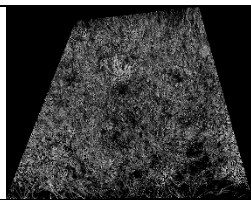
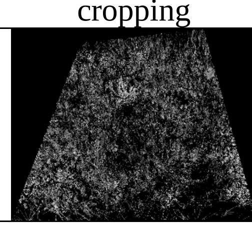
Figure 3-7: Images from Figure 3-6 after ROI cropping, (a) one of the field sites and (b) greenhouse. Due to the angle in the field image (a) the shape is slightly trapezoidal.

Lighting conditions were not always identical for each image, which resulted in some overexposed images or high intensity image elements. For this reason, the visual red-green-blue

(RGB) spectrum was normalized prior to grass identification (Woebbecke, 1995). Equations and code can be found in Appendix A.

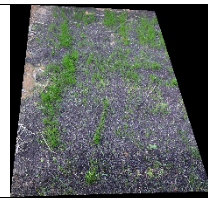
Following spectrum normalization, the image greenness can be extracted using the excess green and excess green minus excess red spectral data. The average of these two values was calculated for over 900 digital images (Table 2). These values were then binned into 256 bins based on the original 8-bit image. The median and mean were then calculated for the binned average greenness values to determine a general threshold to apply to all images.

Table 2: Image manipulation for Greenness calculations. This follows a single image from the Hanover, MD site through the entire calculation process. Average greenness for all images was calculated and used to determine a final thresholding value.

		
Original image	Image normalization with cropping	Excess red ExR = 1.4*r-g
		0.2256
Excess green ExG = 2*g-r-b	Excess green without excess red ExGR = ExG - ExR	Average pixel value of the two green images

Percentage of greenness was then calculated for each image based on the thresholding median and mean values calculated, examples of these values are presented in Table 3. Also included in this table is the maximum possible greenness calculated from the simple assumption that a green pixel will always have a larger G spectral value than the R or B spectrums. This assumption begins to no longer represent grass when the red and/or blue spectrum values begin to approach the green value. For the purpose of this study, the median greenness value, as calculated above, was chosen as the thresholding value for all images. This reduces the effects of outliers and possible interferences from the other visible spectrum values.

Table 3: Percent green grass coverage based on two different thresholding values and an RGB, G spectral maximization method.

Image				
Median based coverage (%)	7	21	34	89
Mean based coverage (%)	3	17	28	86
Max green based coverage (%)	2	33	54	92

SAMPLING

Stomwater quality and vegetation growth were both monitored through water sampling, sediment capture, and grass height measurements. One -L Thermo Scientific storm water sample bottles were placed at the bottom of eight different slopes in each of the two field locations, with a wooden weir set up to divert storm water from the slope into each container (Figure 3-8). 5 in. by 11 in. Muslin bags purchased from Maryland Homebrew were used to capture sediment at both field sites based on the method derived from Hsieh et al. (2009). Each bag was 5 in. by 11 in. and had a mesh size of ~1 mm to allow water flow through but capture large sediment. Three bags were placed at the bottom of each slope with a total of 45 bags/site. Bags were placed at the left, middle, and right sides of each plot (Figure 3-8). Each bag was opened to cover 6 in of space at the bottom of the slope with a total of 18 in.; this accounts for 25% of each slope at Hanover and 19% of each slope at Upper Marlboro.

All bottles and bags were picked up and replaced every two weeks or after major storm events. Sediment samples from the bags were dried and weighed for total sediments captured. Water samples were analyzed for total phosphorus (TP) and total nitrogen (TN). Grass height measurements for all slopes were measured using a metal yard stick. Three measurements were made semi-randomly, left, middle, and right, within each 45 in. segment at the two field sites. This resulted in 12 measurements for Hanover, MD and 30 for Upper Marlboro, MD. These values were averaged over the entire slope.

All runoff from the greenhouse synthetic storm experiments was collected and analyzed for sediment concentration, TN and TP, and N and P speciation. Periodic grab samples were also taken throughout each storm event to determine any trends that may develop within the individual events. These grab samples included the first flush, a 10-15 min. grab sample, a 20-25 min. grab sample, and a 30-35 min. grab sample. The remainder was collected in a large 5-gallon container and analyzed as a composite sample. Similar to the field measurements, grass heights were measured using a metal yard stick with three measurements taken at the bottom, in the middle, and at the top of each slope. In both the field and greenhouse studies, there were instances where runoff volume was not large enough for analysis, and these situations were labeled as NS for no sample.

Figure 3-8: a) First flush water runoff sampling container. The weir was added to collect a larger volume of runoff from the slope for testing. b) Cheesecloth sediment bags for soil collection.

ANALYTICAL PROCEDURES

Due to the collection process/holding time for field water quality samples, it was not advisable to measure nitrogen and phosphorus speciation since sample species characteristics were likely to have changed before accurate measurement; therefore only totals for nitrogen and phosphorus were measured. However, complete analysis was done for all greenhouse collected samples which included: TN, TP, nitrate, nitrite, ammonium, soluble reactive phosphorus (SRP), dissolved phosphorus (DP), and sediment concentration (TSS).

Volume: Mass Relationships

All field and greenhouse media were mixed and loaded on a volume basis, which is largely dependent on the moisture content of the media. This is critical for compost as the moisture holding capacity is much larger than topsoil. Volume-based loading was subsequently converted to dry mass loads, based on moisture content and bulk density measurements made for each medium. Four different volumes between 50 mL and 250 mL were weighed to determine a bulk density with a 5-L measurement to ensure consistency at larger volumes. All measurements were averaged to determine the medium bulk density. Samples were then weighed, in triplicate and placed into a 104^{o}C oven for 24 hours and re-weighed to determine moisture content of each medium to calculate the dry medium mass loaded.

WATER QUALITY PARAMETERS

All glassware was washed with tap water and Alconox soap, rinsed with deionized (DI) water then placed in an acid bath for a minimum of 4 hours before being rinsed with DI water and allowed to air dry. Colorimetric measurements were taken on the Cary 60 UV-VIS; this includes TP, DP, SRP, nitrite, and ammonium tests. Any samples outside of the standard curves were diluted to fit within the range of standard values; 0-2 mg/L for TP, SRP, ammonium, and nitrite; 0-5 mg/L for DP; and 0-100 mg/L for TN. Measurements below the detection limit of the test were presented as half the stated detection limit ("AMC Technical Brief" 2001), for all tests this detection limit was 0.05 mg/L. This occurred largely for nitrite measurements.

Total N and P measurements were taken with unfiltered shaken samples for all field and greenhouse samples. All speciation measurements were taken after vacuum filtration through a 0.22-μm membrane to remove suspended particles. Samples that were not immediately measured were stored at 4^oC.

Rainfall data for the field sites was collected from the PRISM climate group at 39.1558 latitude and -76.6769 longitude and 38.7978 latitude and -76.7391 longitude for the Hanover, MD and Upper Marlboro, MD, respectively (Northwest Alliance for Computational Science and Engineering 2013). Hourly precipitation data was also obtained from the National Centers for Environmental Information (NOAA) using their Local Climatological Data (LCD). The nearest location for this information came from Baltimore Washington International Airport, MD (BWI) for the Hanover location, approximately 1.5 miles from the site, and Washington Reagan National Airport, VA (DCA) for the Upper Marlboro location, approximately 21 miles from the site.

Simulated rainfall in the greenhouse studies was tap water supplied by the UMD greenhouse facility. The tap water had average nutrient concentrations of $1.78 \pm 0.3 \frac{mg-N}{L}$ and $0.28 \pm .05 \frac{mg-P}{L}$. The majority of the nitrogen was in the form of nitrate at $77 \pm 5\%$ and the majority of the phosphorus was SRP at $88 \pm 8\%$.

Sediment

Sediment measurements for the greenhouse studies followed the total suspended solids (TSS) standard method (2005) using 30-50 mL of stormwater sample. Some samples contained settleable solids which were rinsed from the container with additional DI water to ensure all solids from the sample were accounted for. Measurement results are presented as $\frac{mg-Solids}{L}$ for grab samples and EMCs and mg-Solids/ft^2, or solids per area of slope, for mass transport.

The mass of sediment in field bags was calculated based on the average from all three bags at each slope and the three slopes of similar treatments. The result is presented as mg-Solids/ft^2. Slope coverage was adjusted to account for bags that were lost during sampling.

Phosphorus

Total phosphorus was measured using the persulfate oxidation method and the ascorbic acid method based on the Murphy and Riley (1977) colorimetric method. SRP was also measured using the ascorbic acid method without oxidation. Both TP and SRP were measured between 0-2 mg-P/L. DP was measured using an Inductively Coupled Plasma-Optical Emission Spectrometer

(ICP) on a range of 0-5 mg-P/L. All standards were created using a stock solution of Lab Chem Inc. 1000-ppm phosphate as phosphorus.

Particulate P and dissolved organic P were both calculated from the TP, DP, and SRP measurements based on equations presented in Appendix A.

Nitrogen

Both nitrate and TN standards were made using a 1000-ppm nitrogen as nitrate stock solution. Measurements for TN were made using a Shimadzu SSM-5000A with a total nitrogen measuring unit. Nitrate measurements for filtered greenhouse samples were measured using ion chromatography on a Dionex ICS-1100 with ASRS 4 mm suppressor and a Dionex IonPac AS22 column. Ammonium and nitrite were measured based on methods found in Clesceri et al. (2005) using only 10 mL of sample in each method instead of the requested 25 mL; the methods were altered to accommodate the reduced sample volume. The 4500-NH_3 F Phenate method and 4500-NO_2-B Colorimetric Method (Clesceri et al. 2005) were used for ammonium and nitrite, respectively. Ammonium and nitrite standards ranged from 0-1 mg-N/L and were prepared from a 5 mg-N/L stock solution produced from ammonium chloride (A649-500) and sodium nitrite stock solutions, respectfully. Organic nitrogen was calculated using the TN and all nitrogen speciation based on equations presented in Appendix A.

Mass Transport

The volume of each sample bottle and the cumulative bucket collected in the greenhouse studies were totaled to produce the volume of effluent runoff. Each sample bottle volume was then multiplied by the concentration measured to produce the total mass transported for that sample and nutrient. When total mass transported per sample container were measured, they were totaled and divided by the total volume collected to calculate an overall event mean concentration (EMC) for that storm event. This EMC measurement is the average concentration of nutrients produced throughout the storm.

For comparison, both field and laboratory samples are presented as the mass of sediments transported and captured per foot of slope width during the observed time intervals.

STATISTICAL ANALYSIS

The Mann-Kendall Tau, Student’s and Welch’s t-tests, and modified Thompson tau tests were used to analyze trends, determine independence and significance of data, and eliminate any outliers within the data measurements. Analysis occurred within specific storm events as well as throughout the entire trial. All hypotheses were rejected or accepted using a significance level of 10% ($p<0.1$). Equations explaining each test are inserted into Appendix A.

Mann-Kendall Trend Test

Trends within data sets were determined using the Kendall Tau one-tailed test. This test is used to determine general increase or decrease in data values with the null hypothesis being: no discernable trend in the sample data and sample concentrations do not change over the x-axis (Daniel 1990).

T-test

Sample independence was determined using the student's t-test or Welch's t-test. These tests are designed to compare the average between two different sample sets with varying treatments. A one-tailed test was used here with the T distribution to determine acceptance or rejection of the hypothesis that the two samples are from the same set (Welch, 1947).

Modified Thompson Tau test

The modified Thompson Tau test was used to determine single variable outliers in sample sets with n variables. Sample points that may have been outliers were tested individually using the τ-distribution with the degrees of freedom equal to n-2. Samples outside of the Thompson τ value were eliminated systematically and a new τ value was calculated until all values fit within the range (Cimbala 2011).

4. Research Findings

Grass Coverage

The following results for cover are based on the method developed in the image capture and analysis section. The median greenness value was used as the thresholding limit for all images. Values only represent green grass and do not include coverage due to straw, dormant grass, or other materials. Field and greenhouse observations were taken every two weeks for 435, 402, 77, 69, 79, and 77 days after initial establishment for Hanover, Upper Marlboro, and the four greenhouse 20:1, 2:1, 4:1, and 4:1 with compost/topsoil experiments, respectively.

Three visible growth periods were seen during the field monitoring phase: Fall 2016, Spring 2017, and Fall 2017; these growth periods can be seen in Figures 4-1 and 4-2. Green coverage reaches a maximum around 90, 300, and 400 days for both field sites; these correspond to early November, early May, and mid-September. During the initial phase of growth, Biosolids, at the Hanover site, and Topsoil, at the Upper Marlboro site, had higher rates of grass establishment than the other medium applications. During this initial establishment, there were no other significant differences between treatment methods; however, the second growth phase showed that greenwaste and the 2:1 mixture of topsoil and greenwaste were slower to reach the maximum greenness. The growth differences occur at both locations, but it is much more evident at the Hanover location (Figure 4-2).

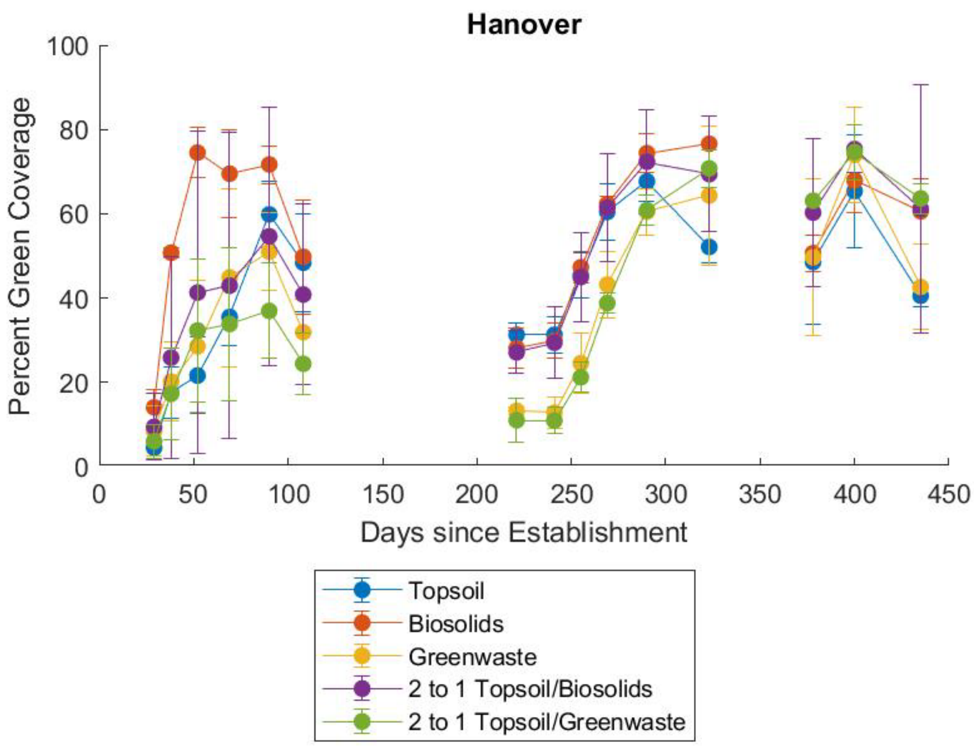


Figure 4-1: Hanover, MD greenness values for the three distinct growth periods. Green coverage after the second growth period becomes statistically similar for both biosolids media types and the topsoil/greenwaste mixtures.

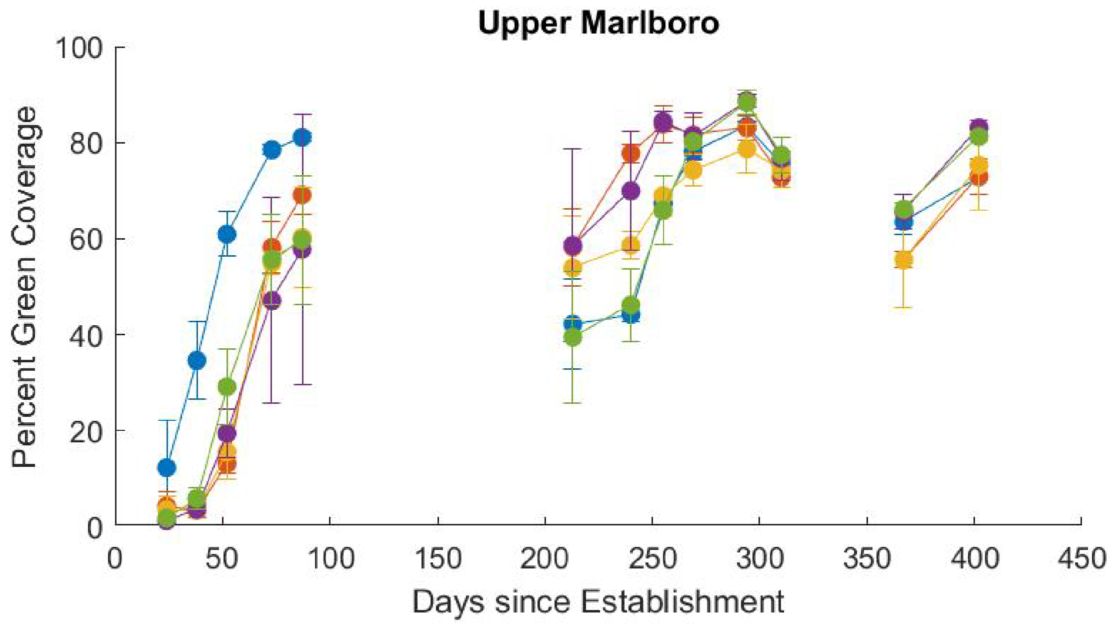


Figure 4-2: Grass growth coverage for Upper Marlboro. As time progresses the variation within each point is reduced and the differences between coverage for each treatment become less significant.

The data in Figures 4-1 and 4-2 use the mean green cover for each slope with the deviation coming from the differences between the three slopes with the same treatment. Not shown in these figures is the high degree of variability in coverage within each slope. Consistently seen from both the field and greenhouse elements of the study was a negative trend in green cover with distance from the base of the slope. This is especially evident with the Upper Marlboro site during the early stages of growth, due to slope length and the number of photos taken. When coverage is near 0% or near 100%, the trend becomes less evident. As images are measured further from the base of the slope, their values begin to decrease (Figure 4-3). In each of the sets of values below, the slope of the fitted line is slightly negative and has a decreasing trend based on the Mann-Kendall trend test. Figure 4-4 gives an example of the slight decrease in green vegetation with distance from the bottom of the slope.

This negative trend is likely due to migration of both moisture and nutrients through the soil media. Both elements along with sunlight are essential to grass growth, based on the process of photosynthesis. All slopes within a site likely received the same daylight hours, and each produced runoff volume with measurable nutrient concentrations. This would indicate that there is moisture and nutrient movement within the media that could create a richer growing environment toward the base of the slope.

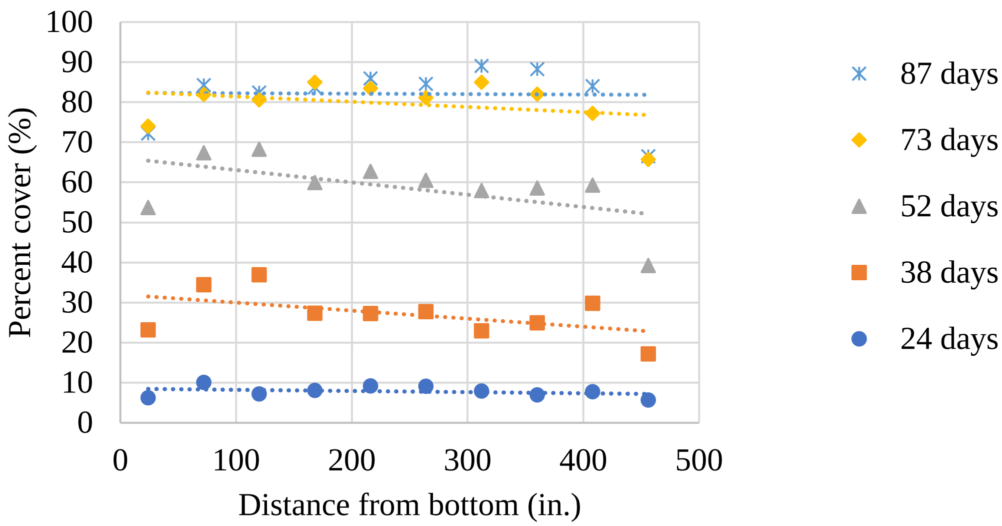


Figure 4-3: Growth with respect to distance from the bottom of the slope. This uses 5 days of coverage for a single topsoil slope at Upper Marlboro to show the negative correlation with distance that was seen in all of the greenhouse slopes and Upper Marlboro slopes. The Hanover data only has four points to show changes in coverage from bottom to top and the trend is not as evident.

Figure 4-4: Images from the slope observed in Figure 4-3 at 52 days.

Figure 4-5 is an example of the wide range of values gathered from the field data. The coverage data comes from the topsoil slopes at the Hanover site. This box plot combines the variability produced from the differences between the three treated slopes at the site and the variability found from the bottom to the top of each slope. Ranges are very wide, 50% at some points, and indicate that a single coverage value does not necessarily match the makeup of the entire slope. More examples of the range of data at both field sites can be found in the Appendix C.

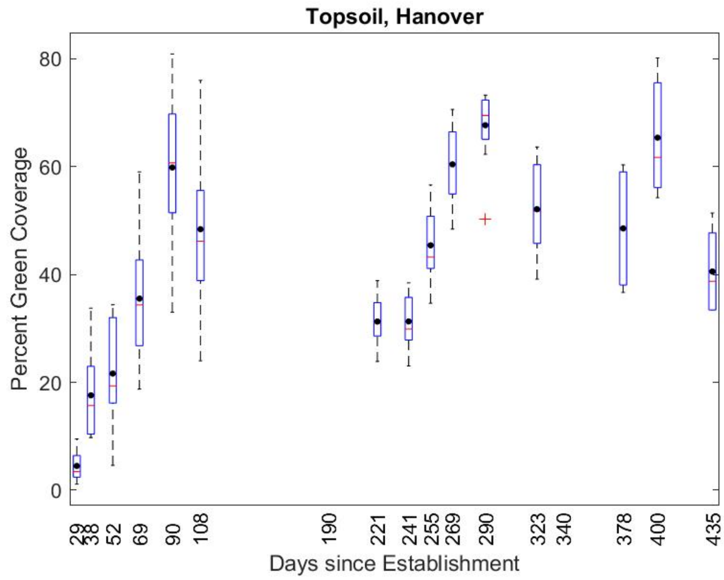


Figure 4-5: Example of growth variability for the Topsoil treated plots at Hanover, MD. This includes all three slopes. The black circle indicates the average value of the data and the red line is the median. Outliers are indicated with a red '+' symbol and are calculated as ± 2.7 *times the standard deviation of 99.3 % of the data, assuming the data is normally distributed.*

The maximum green coverage for both field sites occurred within the first 90 days. Table 4 compares the maximum coverage obtained in the field with the greenhouse values. At similar slopes, field growth was more successful than greenhouse growth across all medium applications (Figure 4-6 and Table 4). In the greenhouse, limited grass growth after 70 days is noted for the topsoil and greenwaste slopes and none for the biosolids slope. After 87 days of growth in Upper Marlboro all slopes show a substantial amount of grass coverage. The coverage values for both composted materials at the 4:1 and 2:1 slope have very low coverage values and did not successfully obtain grass coverage over the trial period.

Figure 4-6: (Left) Greenhouse image after 70 days of growth (Right) After 87 days of growth in Upper Marlboro.

This difference is likely due to lower soil moisture in the greenhouse study compared to the field. A clear difference between the two studies was the amount of rainfall applied with respect to time; frequency and duration of storms along with the drying period between storms was very different. The greenhouse study had consistent 4 in/hr intensity storm events with a 12-day drying period, while the field sites, including multiple days of rain, had average drying periods of 2.8 days with a maximum of 16 days.

Table 4: Percent coverage after 70-90 days of growth. NT: not tested.

				Upper Marlboro	Hanover
Slope	**20:1**	**4:1**	**2:1**	**1.5:1**	**1:1**
Topsoil	70	22	26	81	60
Biosolids	91	3	2	69	72
Greenwaste	94	5	16	60	51
Topsoil / Biosolids	NT	31	NT	58	55
Topsoil / greenwaste	NT	31	NT	60	37

Both field sites received 1.1-1.5 times more water than any of the observed greenhouse studies. All greenhouse slopes received 9 in. of water while the Upper Marlboro site received 9.8 in. and Hanover received 13.7 in. This water was also applied more frequently at lower intensities which could indicate that the limited success establishment in the greenhouse studies was due to soil moisture. Before and after greenhouse storm application, the soil moisture was measured for each plot. For the 20:1 slope trial, grass establishment was highly successful, between 70-94% coverage, and soil moisture content before storm application was 28$\pm$7%, 22$\pm$7%, and 8$\pm$4% for greenwaste, biosolids, and topsoil, respectively. However, when the slope was increased to 2:1, grass establishment was between 2-26% coverage after the 69 days. At this slope, soil moisture content decreased to 13$\pm$1%, 15$\pm$6%, and 2$\pm$0.3% for greenwaste, biosolids, and topsoil, respectively.

WATER QUALITY

Total nitrogen and phosphorus were measured for all field and greenhouse studies, but TN and TP speciation were only measured for greenhouse samples due to the length of time field samples were left in the field before measurement. Field samples represent the first liter of water collected from the slope runoff and do not indicate the total volume of runoff or the total mass of the transported nutrients. All of the runoff from the greenhouse studies was collected and measured.

All treatments showed some degree of rainfall infiltration, with steeper slopes generally producing greater runoff volume. The biosolids compost was the most successful at reducing the runoff volume. Compared to the current MDOT SHA topsoil application methodology, biosolids application reduced the runoff by 40-98%. Conversely, the topsoil/greenwaste mixture produced the most runoff with 95% more than the MDOT SHA topsoil (Table 5).

Runoff volume is largely determined by the infiltration rate of the soil; faster infiltration produces lower runoff. The infiltration rate at any point can be calculated using the hydraulic conductivity and water content of the soil media. Many studies use soil grain size and particle density to empirically derive the hydraulic conductivity of a soil and have found the two to be positively correlated, larger particle sizes produce larger hydraulic conductivity (Arya and Paris 1981; Vukovic, 1992). This is likely a major factor in the reduction of runoff volume found with the use of biosolids. From the measured distribution (Figure 3-2), the biosolids compost media has the largest particle size distribution which would indicate greater capacity for infiltration.

Table 5: Volume (L) of effluent collected or applied to each greenhouse study. NT: not tested.

Slope	**20:1**	**4:1**	**4:1**	**2:1**
Applied	339	330	330	304
Runoff				
Topsoil	2.6	4.9	4.6	55.5
Biosolids	0.1	2.9	NT	1.2
Greenwaste	8.6	7.3	NT	15.5
Topsoil / biosolids	NT	NT	71.4	NT
Topsoil / greenwaste	NT	NT	101	NT

The reduction in infiltration seen in both the exposed compost/topsoil mixtures is in part due to the reduced soil particle size distribution but is most likely due to soil sealing from rainfall impact. Rainfall intensity and impact can compact soils and increase soil density while reducing the surface hydraulic conductivity (Duley, 1939; Edwards, 1969). This was not seen in the topsoil due to the application of straw mulching as a protection against rainfall impact.

Despite greenwaste compost having the lowest particle size distribution of all medium applications, infiltration reduction was not seen in either of the pure compost amended slopes without straw mulching. Many studies have shown that compost addition to soil has reduced soil bulk density, increased aggregation stability, and improved the soil water holding capacity (Khaleel et al., 1981; Mitchell, 1997; Kirchoff et al., 2003). With improved soil structure the greenwaste soil surface was more protected from soil sealing; this was also seen by Bresson et al. (2001) when studying effects of biosolids compost on crust formation and seedbed slumping.

Sediment Capture

Field sediment capture occurred for 290 days at Hanover and 283 days at Upper Marlboro; at that time ground cover had accumulated to the point that sediment bags were no longer functional and no longer in contact with the soil surface. Some storm events did not produce a large enough volume to transport sediment and bags were left in the field for further collection.

For both locations there was no discernable trend in data when compared to total precipitation applied. Although the overall averages of the sediment data revealed higher concentrations of sediment loss from both biosolids/topsoil and greenwaste/topsoil applications, 0.9 $\frac{g}{ft^2}$ and 3.2 $\frac{g}{ft^2}$ at Hanover and 8.1 $\frac{g}{ft^2}$ and 8.4 $\frac{g}{ft^2}$ at Upper Marlboro, respectively, these values were not statistically different from other medium applications. There were also no statistical differences between the two sites for the same treatment.

Maximum sediment capture at the Hanover site for topsoil, greenwaste/topsoil, and biosolids/topsoil was measured after 13 in. of rainfall on 10/4/16; sediment masses were $0.60 \pm 0.12 \frac{g}{ft^2}$, $3.2 \pm 0.33 \frac{g}{ft^2}$, and $0.94 \pm 0.16 \frac{g}{ft^2}$, respectively (Figure 4-7). This date correspond to the maximum sediment capture at the Upper Marlboro site as well, for greenwaste, biosolids/topsoil, and greenwaste/topsoil with only 8.3 in. of rainfall; sediment measurements were $3.9 \pm 1.3 \frac{g}{ft^2}$, $8.1 \pm 1.9 \frac{g}{ft^2}$, and $8.4 \pm 3.1 \frac{g}{ft^2}$, respectively (Figure 4-7 and 3-8). On 9/29/16 and 9/30/16 both Hanover and Upper Marlboro received two days of heavy rainfall, 1.5 in. and 1.6 in. at Hanover and 2.3 in. and 1.2 in. at Upper Marlboro. Based on hourly measurement taken at BWI and DCA, rainfall occurred for the majority of both days with a maximum hourly measurement of 0.7 in. and 0.4 in. of precipitation, respectively. Although the hourly precipitation does not denote the maximum intensity during the storm event, it does indicate larger volumes of water over a shorter period of time which corresponded to large sediment mass transport.

Another large sediment capture occurred on 5/12/16 for greenwaste at Hanover after 33 in. of rainfall, $0.32 \pm 0.04 \frac{g}{ft^2}$, and topsoil and biosolids at Upper Marlboro after 26 in. of rainfall, $0.50 \pm 0.11 \frac{g}{ft^2}$ and $0.61 \pm 0.06 \frac{g}{ft^2}$, respectively (Figure 4-7 and 3-8). On 5/5/17 and 5/6/17 both Hanover and Upper Marlboro experienced large rainfalls, 0.8 in. and 0.6 in. and 0.7 in. and 0.6 in., respectively. Again, rainfall occurred for the majority of both days with maximum hourly precipitation recorded at BWI and DCA of 0.5 in. and 0.4 in., respectively, which corresponded to large sediment mass transport.

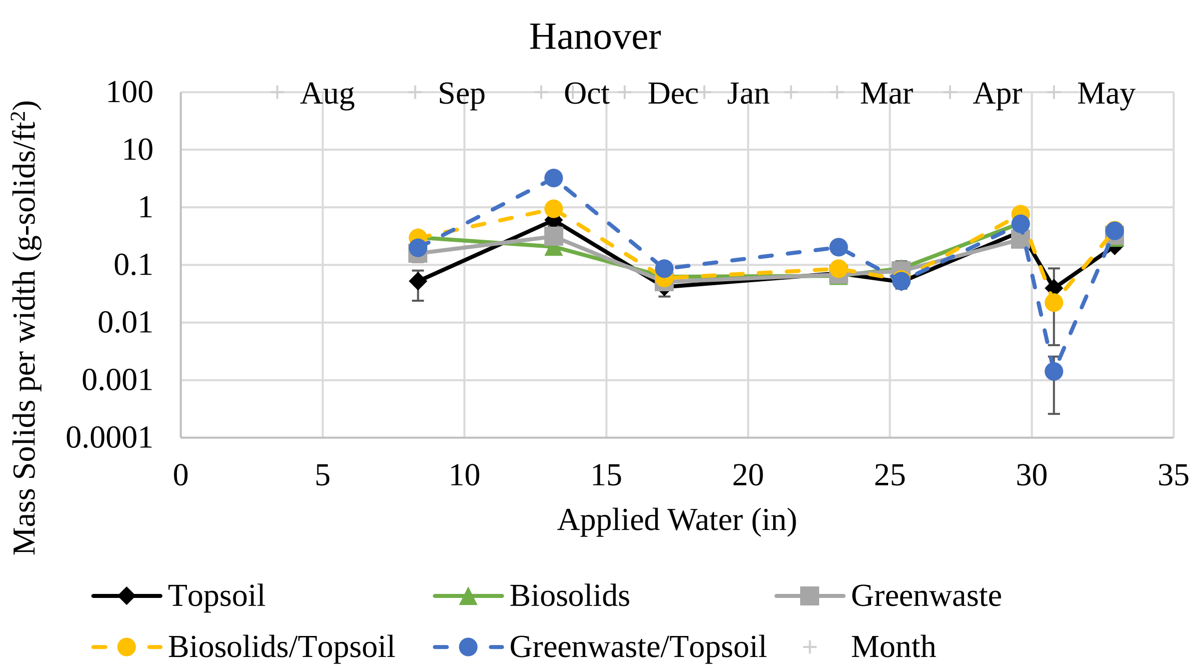


Figure 4-7: Capture of sediment from Hanover slopes. The horizontal axis is set on a log scale to better demonstrate the differences between data sets. There is one instance at 31 in. of applied water where both biosolids and greenwaste produced no sediment runoff.

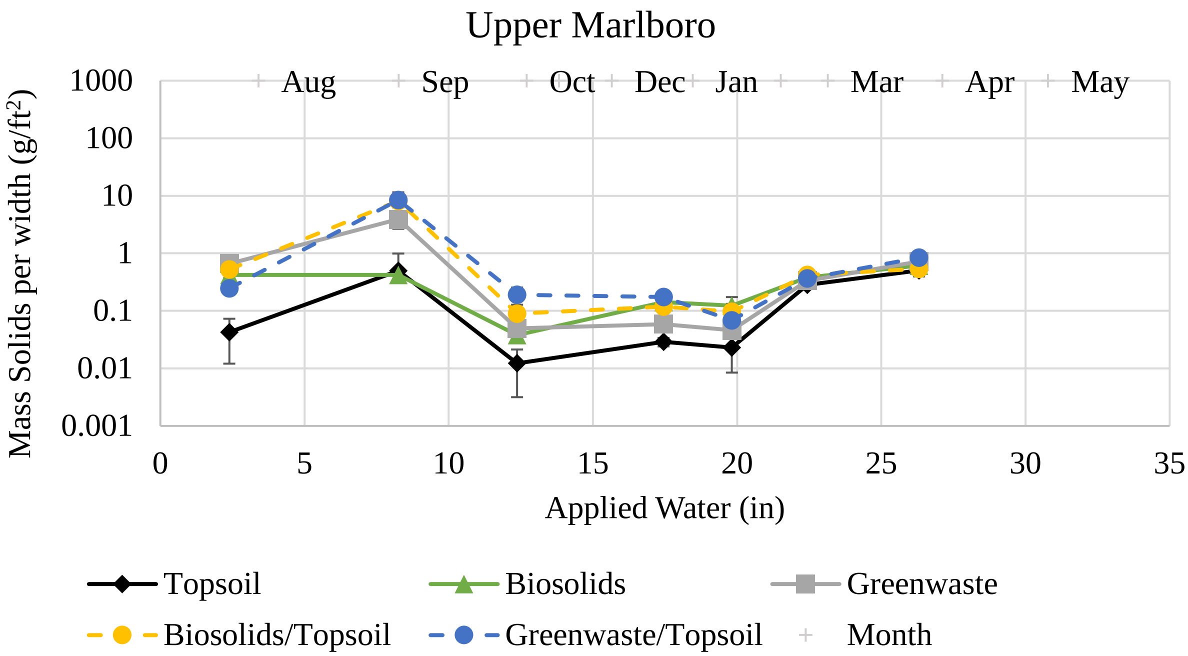


Figure 4-8: Capture of sediment from the Upper Marlboro slopes. The horizontal axis is on a log scale to better show differences in the data set. Although values appear to be larger for both compost/topsoil blends, the difference was not statistically significant.

Similar to the results found in the field, sediment loss for greenhouse studies did not seem to be associated strongly with applied water. Only greenwaste at a 2:1 slope had trending data, EMCs were statistically decreasing. Within storm events there was also limited evidence of a temporal trend in sediment concentration. Only topsoil and greenwaste at the 2:1 and 20:1 slope showed decreasing trends when effluent volumes were large; other events were not as evident (Figure 4-9). At smaller storm volumes, all three applications produced very little runoff and do not show trends. At larger storm volumes, topsoil and greenwaste show negative trends.

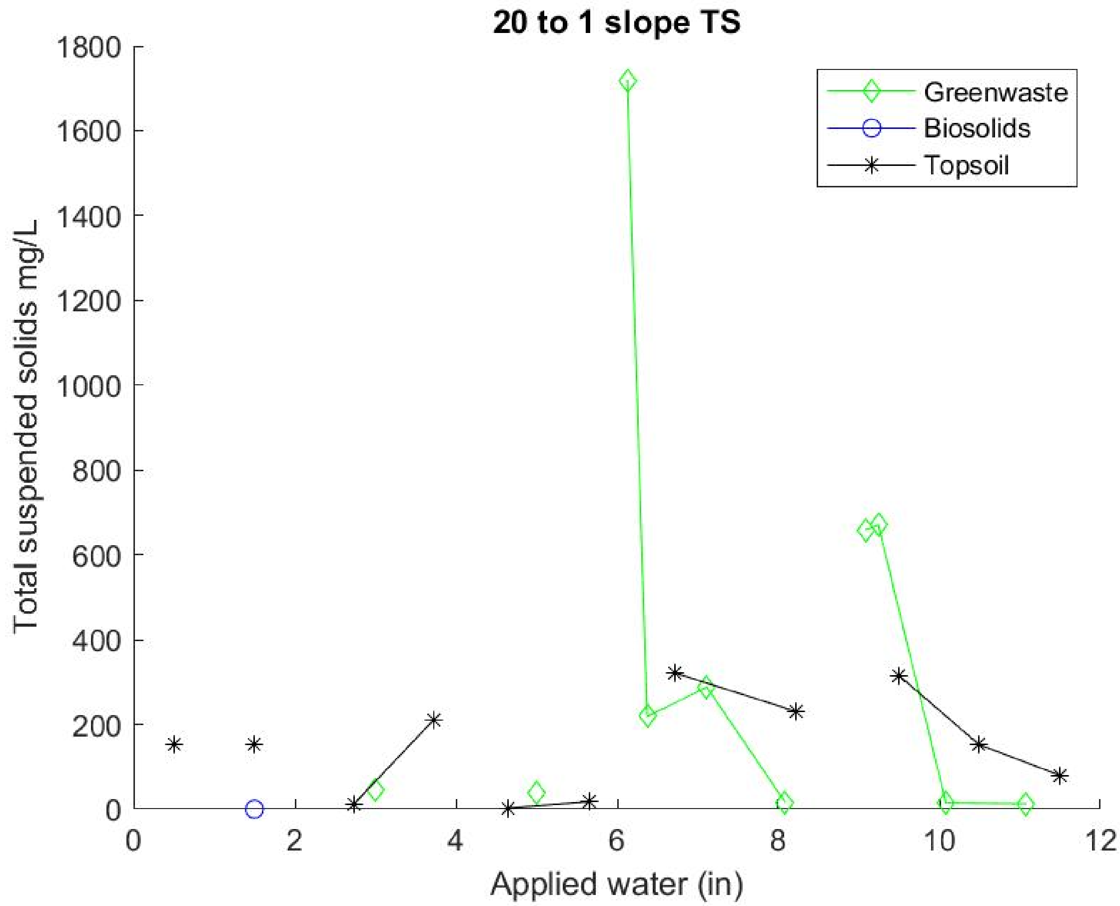


Figure 4-9: Suspended solids concentrations for the 20:1 slope.

Although there were not many significant trends within the data, there were a number of significant differences among the different treatments. At the 4:1 slope, greenwaste/topsoil application consistently produced higher sediment concentrations than all applications but biosolids; the maximum suspended solids concentration produced was $7361\ \frac{mg}{L}$ and a minimum of $752\ \frac{mg}{L}$. Biosolids/topsoil was also statistically lower than the greenwaste/topsoil, maximum $1878\ \frac{mg}{L}$ and minimum $534\ \frac{mg}{L}$, but larger than both topsoil and greenwaste. All other applications were not statistically different. However, there was one instance at the first 30-min storm where biosolids produced a solids concentration less than 1 mg/L (Figure 4-10).

In one or two instances, large concentrations of solids were flushed out that did not necessarily represent the normal sediment transport found in other experiments. This occurred at the 4:1 slope for both biosolids and greenwaste/topsoil at 4 in. and 6 in. respectively, (Figure 4-10). These biosolids and greenwaste/topsoil spikes were 14 and 2 times larger, $10515\ \frac{mg}{L}$ and $7361\ \frac{mg}{L}$, than the second largest solids concentration at that slope, respectively (Figure 4-10). This also occurred for greenwaste at the 20:1 slope $743\ \frac{mg}{L}$ at 7 times the second largest concentration, and topsoil at the 2:1 slope, $3754\ \frac{mg}{L}$ at 2 times the second largest concentration.

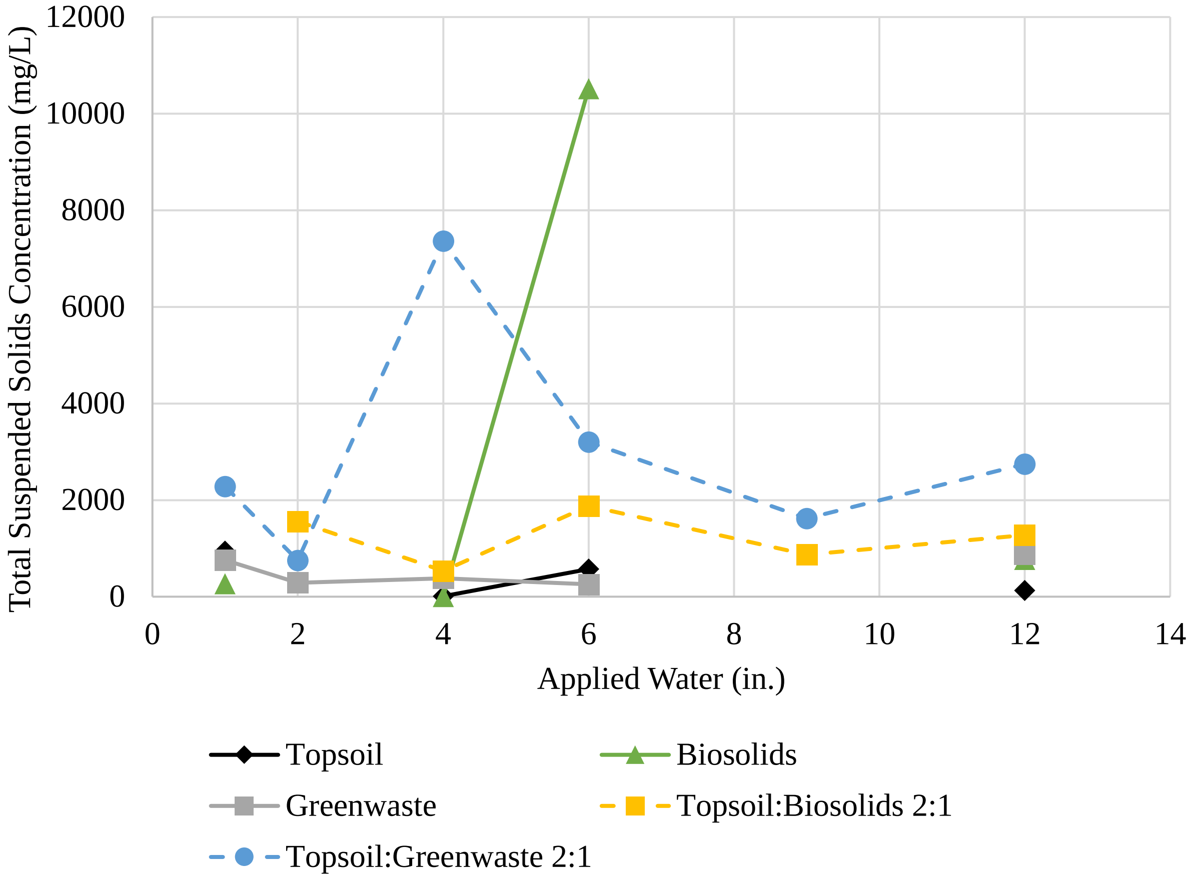


Figure 4-10: Sediment concentrations for all medium applications at the 4:1 slope.

Inadequate runoff volume production was often an issue for biosolids and media at the 20:1 slope (Table 5). Greenwaste at the 20:1 slope for both 15-min storm events and biosolids/topsoil at the 4:1 slope for the first 15-min storm event also had reduced runoff volumes. In these instances, the sample collected was analyzed for nutrients and not sediments.

Comparing greenhouse data on a normalized area basis, there are still no discernable increasing or decreasing trends with respect to applied water, except for the greenwaste at 2:1 slope. However, some of the significant differences between medium applications do change. Greenwaste/topsoil still has the highest concentrations among all applications, between 0.18 $\frac{g}{ft^2}$ and 11 $\frac{g}{ft^2}$, but biosolids/topsoil is not significantly different from topsoil or biosolids, between 0.03 $\frac{g}{ft^2}$ and 2.6 $\frac{g}{ft^2}$, Figure 4-11.

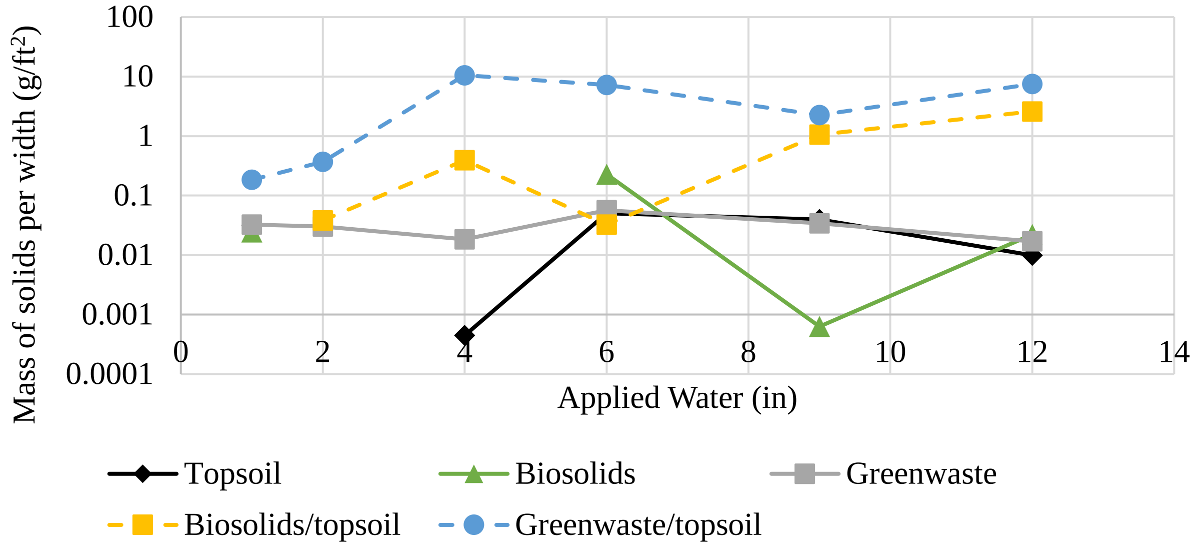


Figure 4-11: Sediment transport for all medium applications at the 4:1 slope. Values are in g-solids/ft^2 based on the area of each slope.

Comparing the field applications to the greenhouse applications, focusing only on the values with overlapping applied water, the sediment transported from greenhouse studies was only statistically lower for biosolids and greenwaste at the Hanover and Upper Marlboro sites. All other comparisons showed no statistically significant differences.

A major process mechanism for sediment transport was seen in the field but not in the greenhouse: the creation of rills (Figure 4-12). This occurred only at the Upper Marlboro site with both compost/topsoil blends. In these instances, the measured sediment capture may be underestimated as the operating assumptions behind the sediment bags were that sheet flow across the surface would be uniform and continuous. Figure 4-12 demonstrates that along the greenwaste/topsoil and biosolids/topsoil slopes, rills were formed and had the potential to transport large quantities of soil through preferential flow.

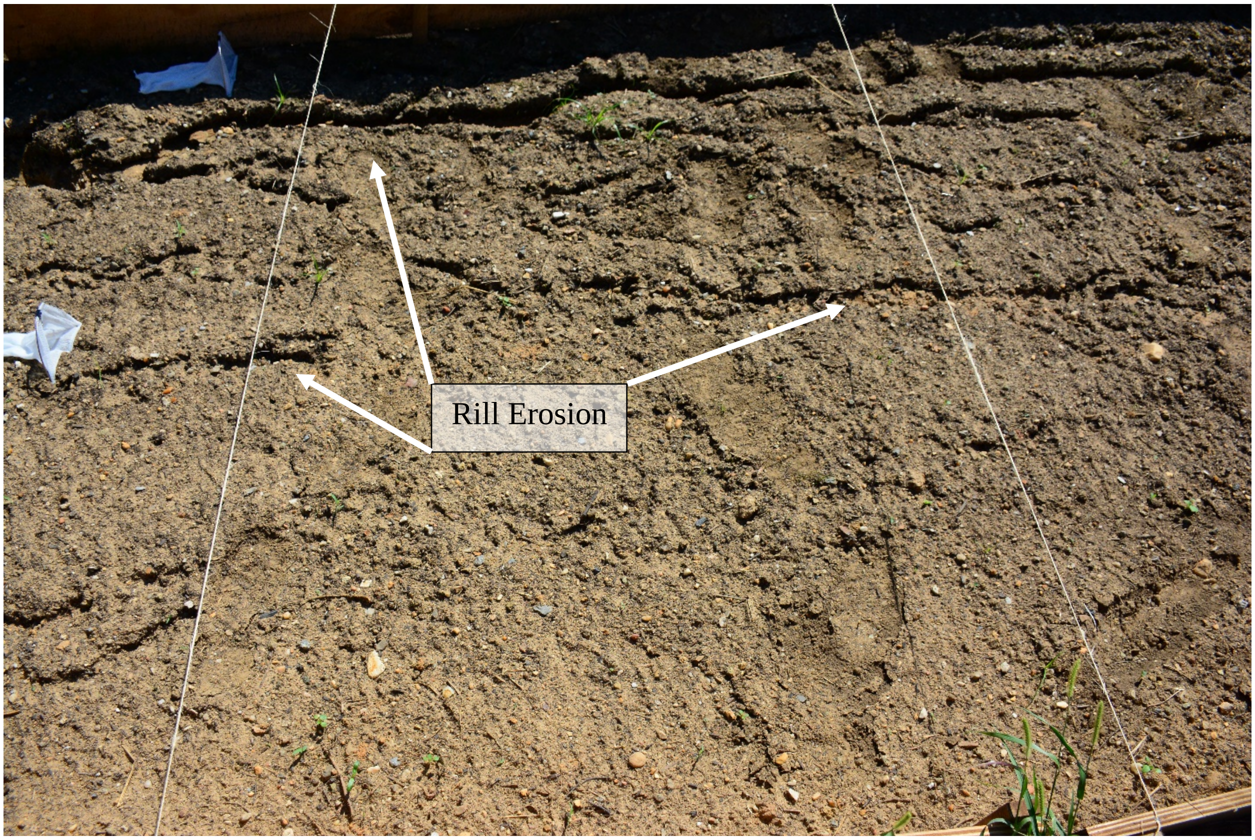


Figure 4-12: Example of rill erosion in one of the greenwaste/topsoil plots in Upper Marlboro. The top most rill avoids the sediment bag placed on the left side of the slope while the middle rill flows into the bag location.

Phosphorus and Nitrogen

Phosphorus measurements for field locations had no discernable temporal trend associated to the data over the 402-day measurement period. This would indicate that effluent leaching values reached a steady state for each plot. Two data points from the Hanover greenwaste/topsoil mixture, one from the topsoil applications, and one from each of the applications at Upper Marlboro were excluded using the modified Thompson tau test for outliers.

Only the Upper Marlboro site showed significant differences among any of the medium applications for P. The Upper Marlboro topsoil, biosolids/topsoil, and greenwaste/topsoil, after outlier exclusion, did not have significantly different average concentrations $0.91 \pm 0.5 \frac{mg-P}{L}$, $0.75 \pm 0.6 \frac{mg-P}{L}$, and $1.5 \pm 1.2 \frac{mg-P}{L}$, respectively. Both topsoil and biosolids/topsoil were significantly lower than both pure compost amendments, $2.2 \pm 0.9 \frac{mg-P}{L}$ and $2.9 \pm 1.7 \frac{mg-P}{L}$ for biosolids and greenwaste respectively, however, the greenwaste/biosolids blend was only lower than the greenwaste amended slope. None of the average leachate concentrations from the Hanover site showed any significant difference within the site, but the topsoil leachate was significantly higher than the leachate at Upper Marlboro.

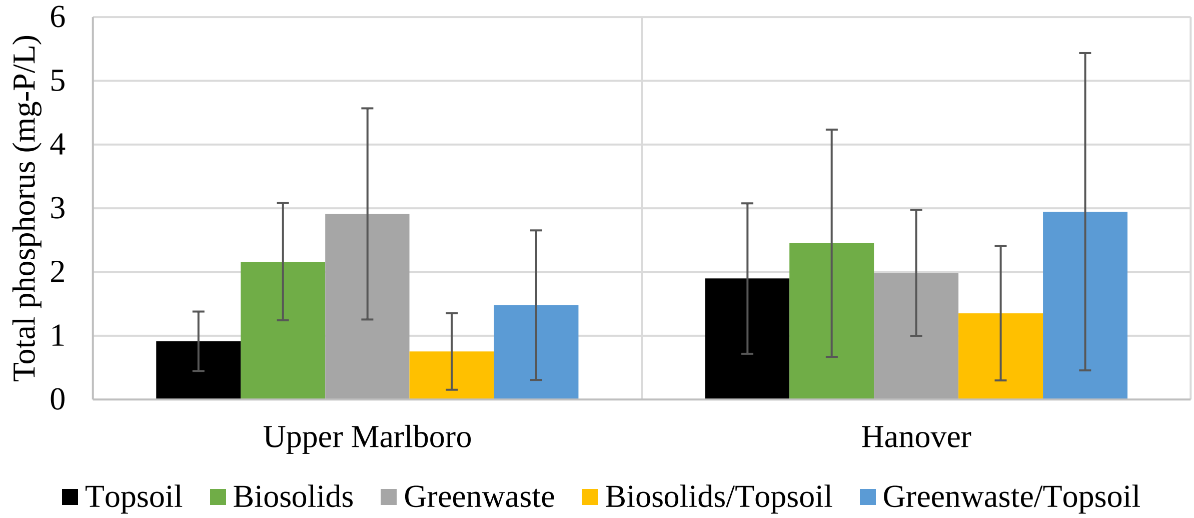


Figure 4-13: Average P concentrations for both Upper Marlboro and Hanover with all outlier points excluded.

Observed often in the greenhouse studies, but not in the field samples was a general decrease in effluent P concentrations as simulated rainfall was applied to the media. This was seen within individual storms for all media, when large effluent volumes were collected, but was also demonstrated in EMC values for topsoil at all slope angles, greenwaste at the 2:1 slope, and biosolids at the 4:1 slope. Neither of the compost/topsoil blends showed EMC reduction with applied water. Effluent nutrient reduction with time was most obvious in the greenwaste application at the 2:1 slope (Figure 4-14). Here both the individual storm flush and the overall EMC reduction can be seen. Effluent TP concentrations for all soil media can be found in Appendix E. Within each applied storm there is also an evident decrease in the concentration of nutrients which quickly reaches a steady state value. This reduction also appears to be independent of grass growth which had a maximum of 16% cover for greenwaste toward the end of the 69-day trial (Table 4).

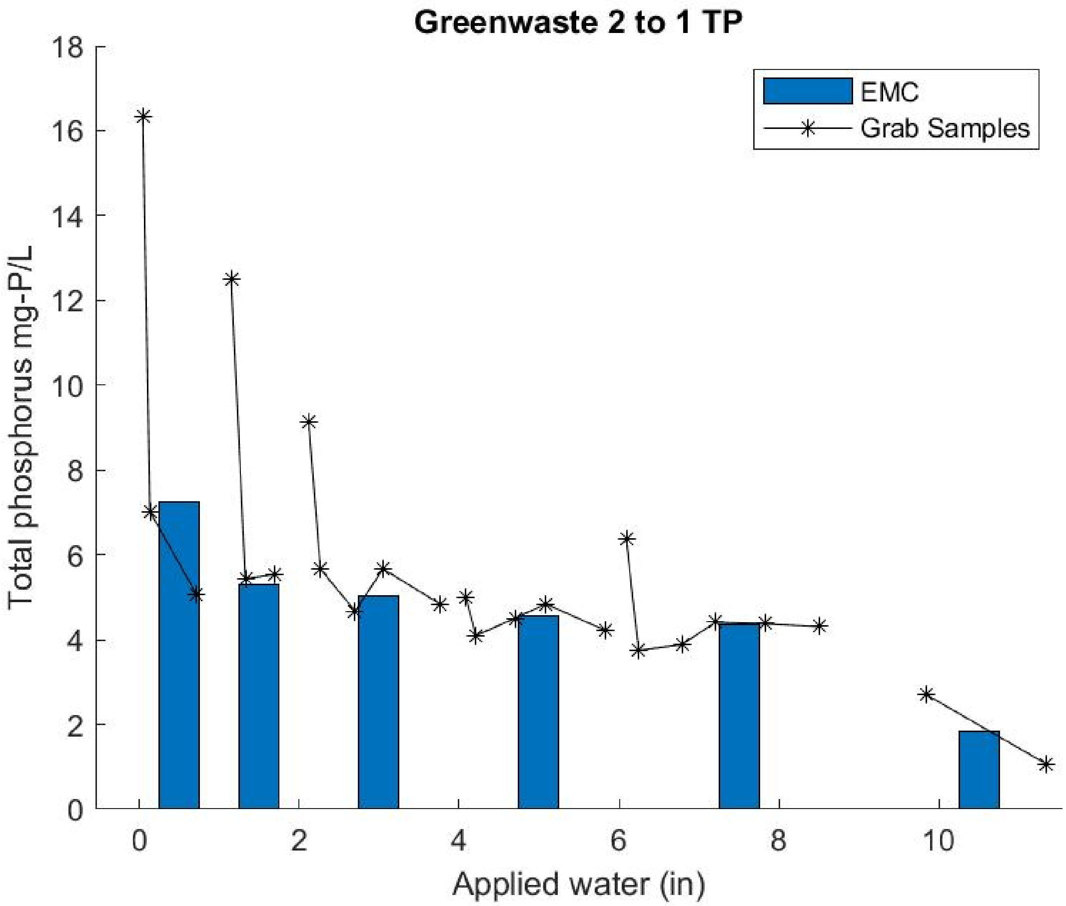


Figure 4-14: P concentrations vs applied water for the 2:1 slope with greenwaste media. An example of nutrient EMC and grab sample values reducing with the application of water.

All five medium applications were tested in the greenhouse at the 4:1 slope. Similar to the results found at the Upper Marlboro site, topsoil, greenwaste/topsoil, and biosolids/topsoil produced statistically lower concentrations of P with applied water than their respective compost type $2.5 \pm 1.2 \frac{mg-P}{L}$, $4.8 \pm 1.5 \frac{mg-P}{L}$, and $3.7 \pm 1.4 \frac{mg-P}{L}$. There was also no significant difference found between the two pure compost applications, $5.3 \pm 2.1 \frac{mg-P}{L}$ for greenwaste and $6.7 \pm 1.5 \frac{mg-P}{L}$ for biosolids, or between the two compost/topsoil blends. However, unlike the field data, topsoil had statistically lower concentrations than both blends, and the biosolids/topsoil blend was not significantly lower than the greenwaste application (Figure 4-15). Topsoil had one initially high data point then continuously lower values.

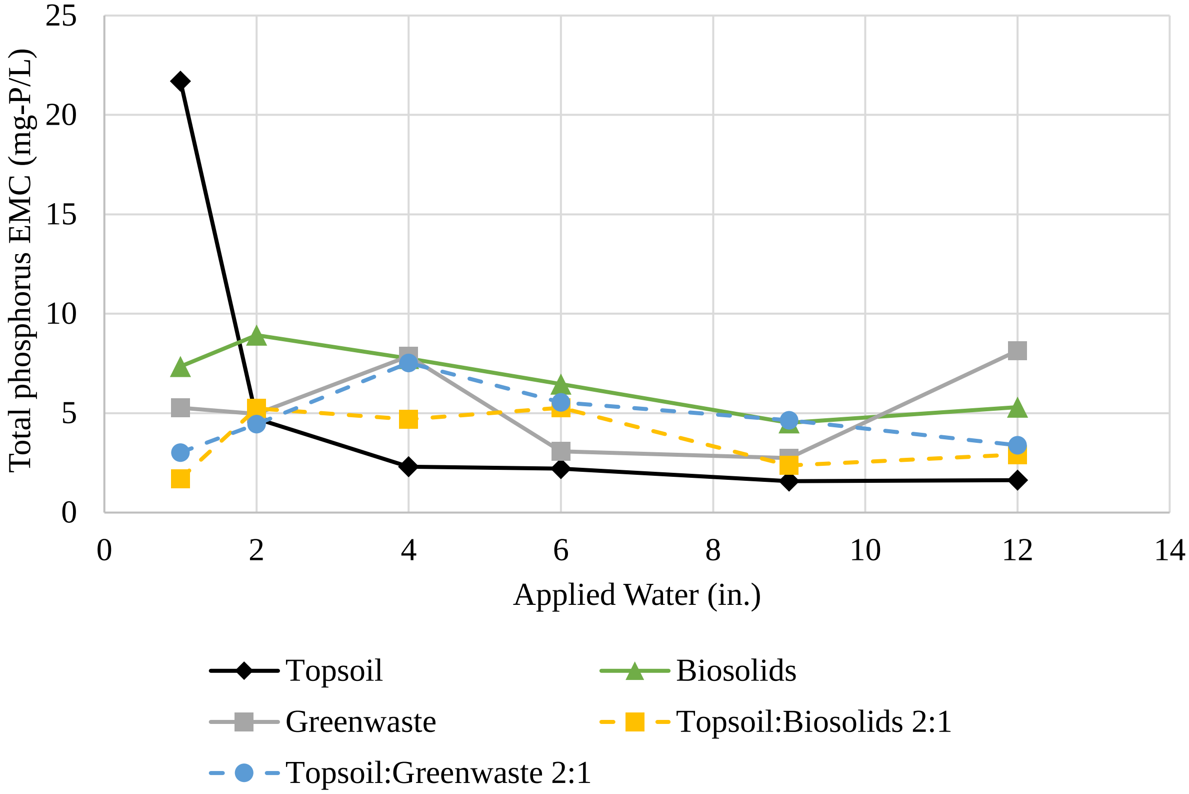


Figure 4-15: P data for all media obtained through the greenhouse study at the 4:1 slope.

The lack of a discernable trend found in the P field data may be due to the volume of applied water and the timing of field measurements. Runoff volumes prior to 3.4 in and 9.1 in of rainfall at Upper Marlboro and Hanover, respectively, were too small to measure P and N concentrations. All decreasing trends found in the greenhouse were measured within the first 12 in. and were most exaggerated within the first 4 in. for both the topsoil and greenwaste slopes. Only one data point from Upper Marlboro was collected within the 4 in. period and three within 12 in. There may have been a decline in P similar to the ones seen in the greenhouse, but samples could not be acquired to demonstrate this change. Also, despite the lack of a decline, observations for all media, except topsoil at Hanover, had statistically smaller values than the accompanying greenhouse P concentrations.

Unlike the field P observations, a N first flush was seen within the first 10-12 in. of applied water at both sites. Initial concentrations were 3-17 times higher than the average concentrations after the first flush. Greenwaste/topsoil at Upper Marlboro had the highest initial concentration of 67.4 $\frac{mg-N}{L}$. Beyond these initial measurements, similar to the P data, there was no discernable trend in observations for any applications, which indicates an initial flush of N followed by a steady state leaching. The first flush is most evident in the Upper Marlboro N data in Figure 4-16. There is a noticeable decrease in the concentration within the first 10-12 in., then concentrations fluctuate around a central point.

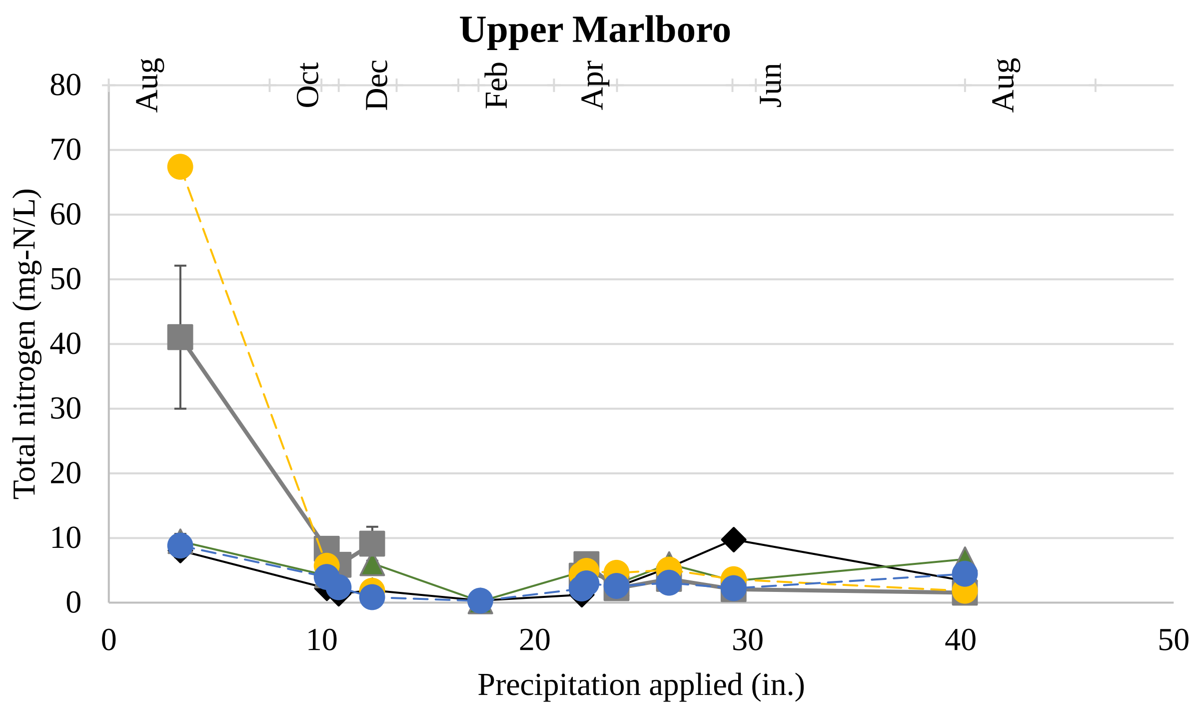


Figure 4-16: Nitrogen concentrations for the Upper Marlboro site. A first flush is seen in the first few samples.

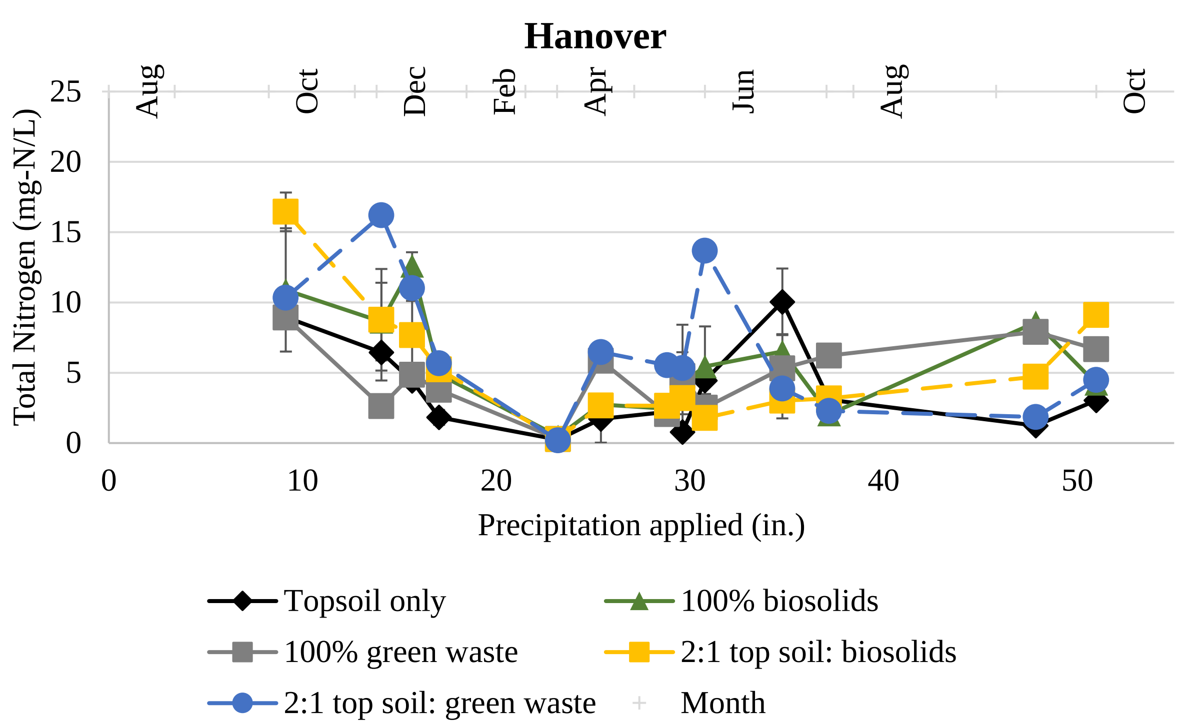


Figure 4-17: Nitrogen concentrations for Hanover. There is not an evident first flush of N like the one seen at Upper Marlboro.

Assuming that values reached a steady state beyond the initial flush within the first 10 in. of rainfall, the remainder of the points can be averaged as the expected leachate of N from each site. Within this steady state, one point from the topsoil, greenwaste/topsoil, and biosolids and three from the biosolids/topsoil applications at the Hanover site and one point from the toposoil and biosolids/topsoil applications at Upper Marlboro were determined as outliers.

Similar significant differences were found for N that were found for P. Topsoil and biosolids/topsoil had lower concentrations than both pure composts at the Upper Marlboro location. Topsoil, biosolids/topsoil, and greenwaste/topsoil were not significantly different from each other, $2.5 \pm 2.2 \frac{mg-N}{L}$, $2.3 \pm 1.1 \frac{mg-N}{L}$, and $4.0 \pm 1.4 \frac{mg-N}{L}$, respectfully. Greenwaste/topsoil concentration was also significantly lower than biosolids compost, but not greenwaste. There was one significant difference found at the Hanover site, topsoil had lower values than all other applications on site ($2.7 \pm 1.8 \frac{mg-N}{L}$); versus (4.0-5.5 $\frac{mg-N}{L}$ for the other media) all of which were not significantly different from each other (Figure 4-18). Also, greenwaste/topsoil was significantly greater at Hanover than at Upper Marlboro, $2.3 \pm 1.1 \frac{mg-N}{L}$ and $5.5 \pm 3.7 \frac{mg-N}{L}$, respectively.

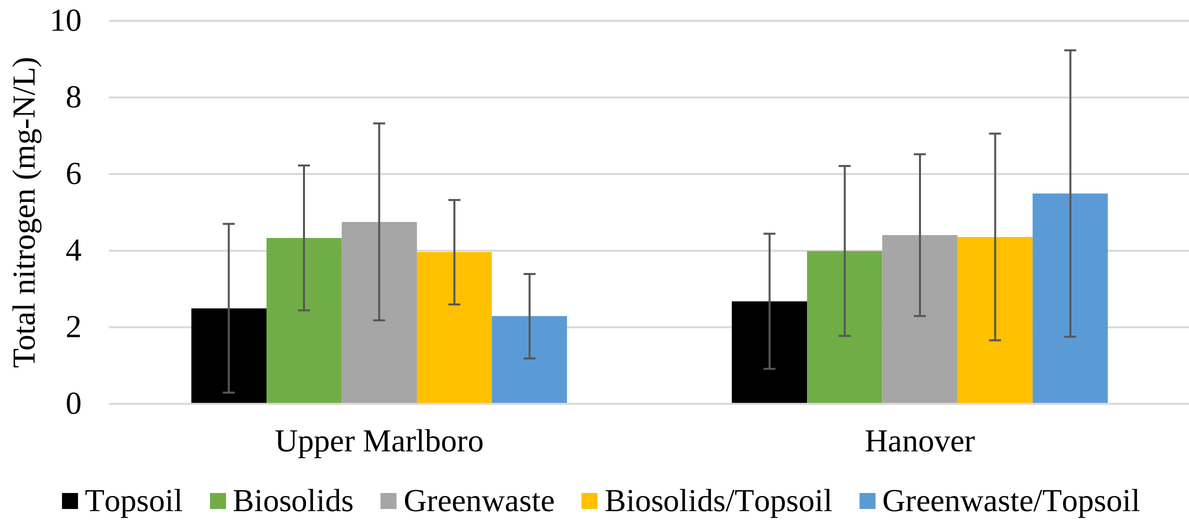


Figure 4-18: Nitrogen concentration averages for the steady state leachate at both field locations. All outlier points are excluded.

The first flush found at both field sites for N was also seen for the greenhouse media. EMC values for all media at the 4:1 slope and the 2:1 slope declined throughout the 12 in. of rainfall. Similar to the greenhouse P data, the concentrations within each storm event (with high enough effluent volume) also produced decreasing N concentrations for all media observed. This is best exemplified in Figure 4-19 for all five applications. Each storm shows an exponential decline in effluent N concentrations for all media, except the biosolids/topsoil between 4-6 in. The greenhouse measurements, along with field data, show that within the first 12 in. of applied water there is a reduction in overall N leaching. It is unknown whether greenhouse data reached a steady state value, similar to the field data, for any medium application since trials did not go long enough. During the 20:1 trial period there was no discernable trend for either the topsoil or greenwaste applications, but biosolids showed increasing concentrations with applied water.

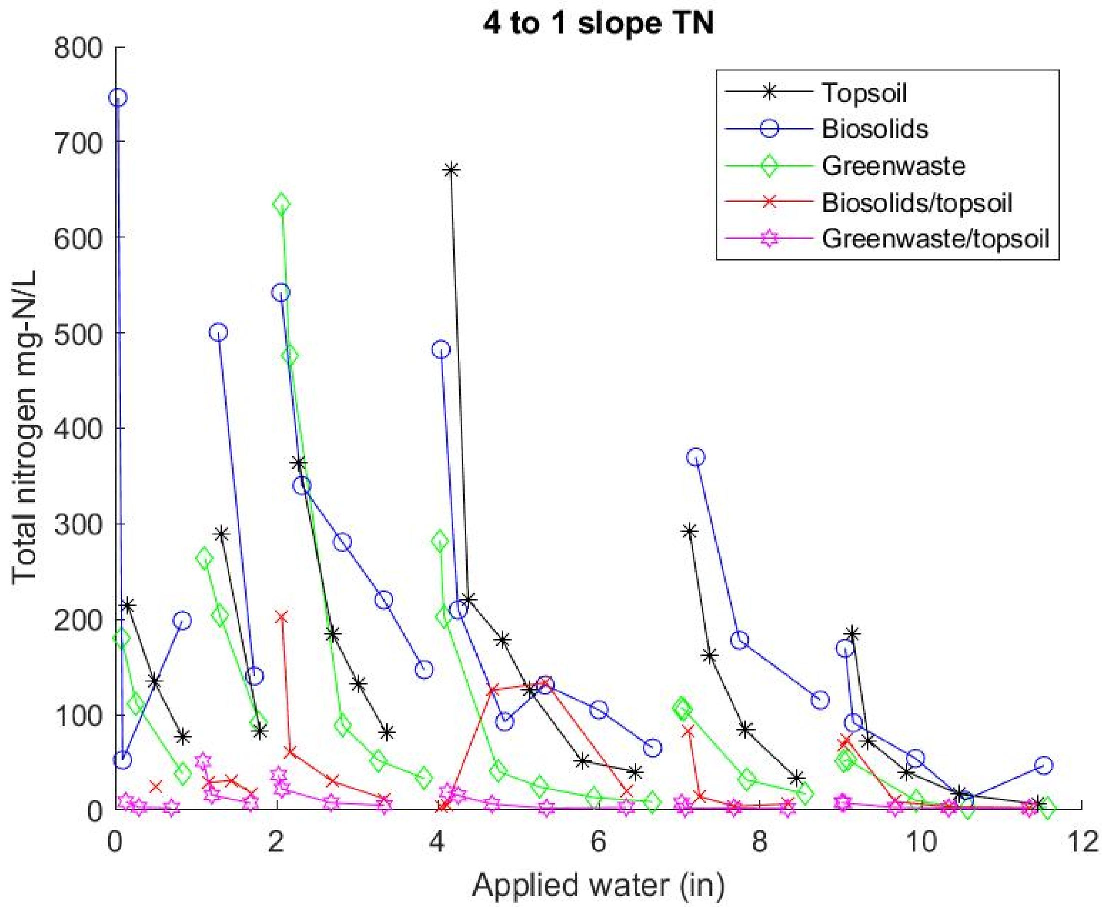


Figure 4-19: N concentrations for all soil medium applications at a 4:1 slope. Single storm events are connected while points represent individual grab samples.

N concentrations for both greenwaste/topsoil and biosolids/topsoil were consistently lower than all other applications, with concentrations between $47\frac{mg-N}{L}$ and $2.4\frac{mg-N}{L}$ and $25\frac{mg-N}{L}$ and $4.8\frac{mg-N}{L}$, respectively. Concentrations for biosolids were consistently the highest, between $480\frac{mg-N}{L}$ and $101\frac{mg-N}{L}$. Greenwaste and topsoil N concentrations were not found to be statistically different at the 4:1 slope and neither were the two compost/topsoil blends when compared to each other (Figure 4-19). Although all media have decreasing trends, biosolids EMC values observe the most change.

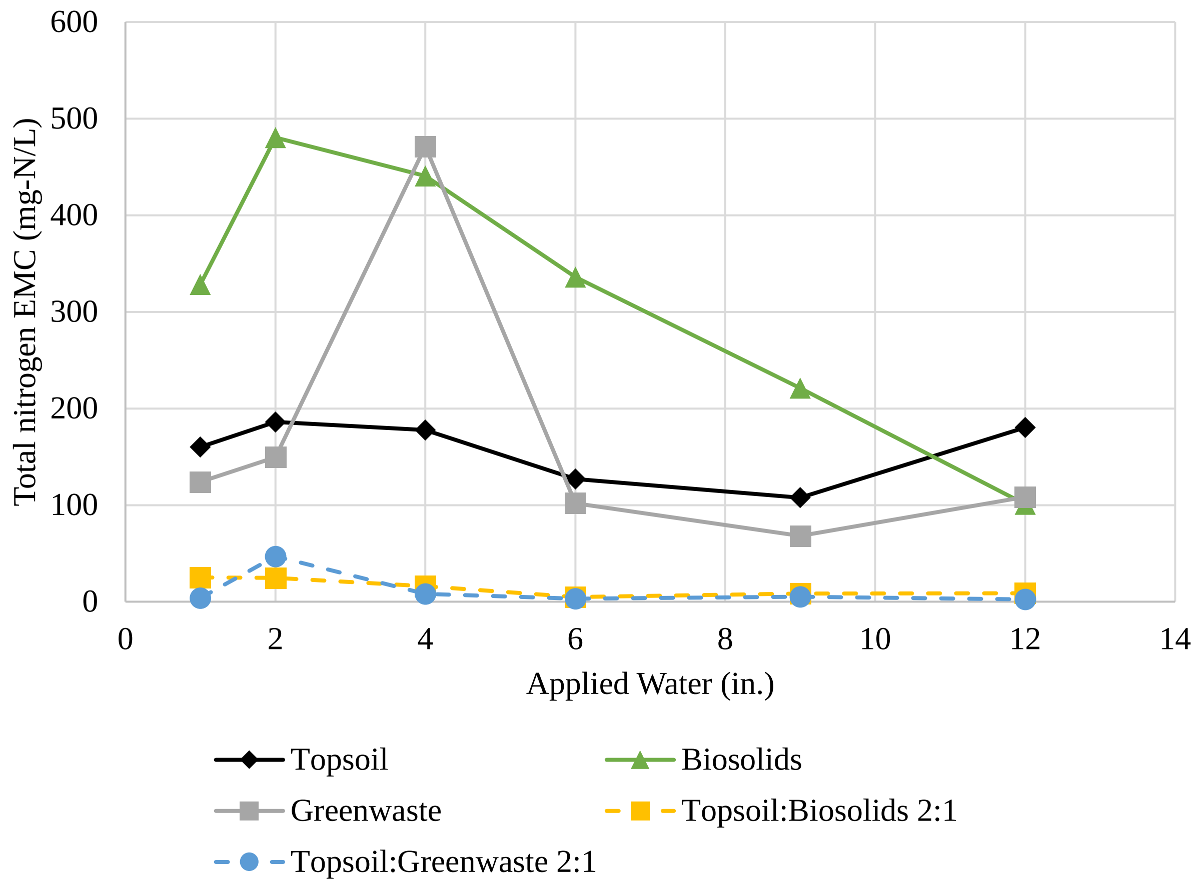


Figure 4-20: N concentrations for all media at the 4:1 greenhouse slope.

On average, all greenhouse N concentrations for topsoil and the pure composts were significantly greater than the field data, but both blends were not. All greenhouse data showed reduction in concentration over 12 in. of applied water. Only the initial 1-3 concentrations collected from the Upper Marlboro and Hanover sites have similar water applications to the greenhouse trials. In Upper Marlboro and Hanover, the first values recorded correspond to 3.4 in. and 9.1 in. of rainfall; Upper Marlboro has a second point that corresponds to 10.2 in. of rainfall.

All pure compost concentrations are greater than the observed field concentrations, 5 to 14 times greater. Both compost/topsoil mixtures, however, had similar concentrations with greenwaste/topsoil leaching 23% less and biosolids/topsoil being within the standard deviation of Upper Marlboro values at similar rainfall. At 10 in. applied water greenwaste/topsoil and biosolids/topsoil were greater than the Upper Marlboro concentrations by 40% and 150% respectively, but both were below Hanover concentrations by 50%.

Greenhouse trials compared the two compost types with the current MDOT SHA topsoil application at three different slopes to determine any slope effects on the leaching of nutrients. The 20:1 slope produced the lowest EMCs and volumes for all soil media, except effluent volume for greenwaste at the 4:1 slope.

The maximum volumes from topsoil, biosolids, and greenwaste at the 20:1 slope were 2.6, 0.1, and 8.6 L versus (comparison values are the smallest maximum between the 2:1 and 4:1 slopes) 4.9 L at 4:1, 1.2 L at 2:1 and 7.3 L at 4:1, respectively. Maximum P concentrations from topsoil, biosolids, and greenwaste were 2.7 $\frac{mg-P}{L}$, 6.7 $\frac{mg-P}{L}$, and 2.5 $\frac{mg-P}{L}$ at the 20:1 slope versus 18 $\frac{mg-P}{L}$, 7.6 $\frac{mg-P}{L}$, and 7.2 $\frac{mg-P}{L}$ at 2:1, respectively. Maximum N concentrations from topsoil, biosolids, and greenwaste were 16 $\frac{mg-P}{L}$, 48 $\frac{mg-P}{L}$, and 82 $\frac{mg-P}{L}$ at the 20:1 slope versus 89, 421, and 230 $\frac{mg-N}{L}$ at 2:1, respectively.

For both topsoil and biosolids, the 4:1 slope produced greater N concentrations than the 2:1 slope, but not significantly different P concentrations (Figure 4-21). Greenwaste did not show significantly different P and N concentration for either slope. More EMC graphs comparing the different slope responses can be found in Appendices D and E.

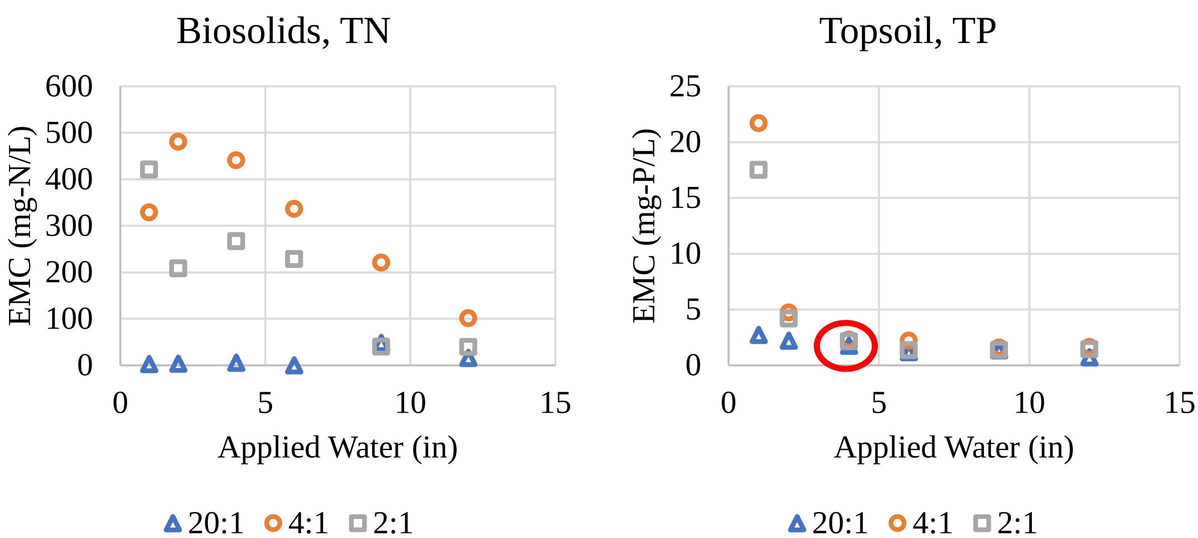


Figure 4-21: Biosolids TN and Topsoil TP concentrations for the three different slopes. The red circle indicates points where the concentrations are beginning to converge for two different slope EMCs.

At 4 in. of applied water both the 4:1 and 2:1 slope for topsoil begin to converge with the 20:1 slope (Figure 4-21). This may indicate both slopes are approaching a stabilization phase where a more consistent effluent concentration is released. For biosolids, although the slopes appear to be approaching one another they do not converge within the 12 in. applied water.

Phosphorus and Nitrogen Speciation

Observations for P and N speciation are based on values obtained from the 2:1 slope. This slope had the most comprehensive breakdown of both P and N species.

For all media, DOP and nitrite were not major components of the effluent P and N. Biosolids effluent had the highest composition of DOP throughout the trial; between 12% and 35% of the total P, with concentrations 0.05 $\frac{mg-P}{L}$ and 0.5 $\frac{mg-P}{L}$ at 12 in and at 4 in of applied water, respectively. Topsoil and greenwaste had DOP concentrations between 0.001 – 1.1 $\frac{mg-P}{L}$

and 0.26 – 0.73 $\frac{mg-P}{L}$ that accounted for 0-18% and 5-15% of the total P, respectively. When nitrite was measured, the concentrations were consistently below 1% of the total N concentration for all soil media with a maximum concentration of 1.0 $\frac{mg-N}{L}$ for greenwaste at 1 in. which accounted for 0.2% of the total N. There was no discernable trend in the release of DOP or nitrite for any media.

On average, SRP comprised the majority of P runoff for both greenwaste (62%) and biosolids (47%); topsoil was mostly particulate P (55%) (Figure 4-22). This was not necessarily the case throughout the entire 12 in. of applied water. After the initial 2 in., topsoil had the lowest total concentrations of P compared to all other media (Figure 4-15). During the first 1 in., the EMC of P was 18 $\frac{mg-P}{L}$ with 80% of that P being SRP, or phosphate, the P form of the fertilizer used during application. This supports the theory that the initial flush seen in the first 2 in. is due largely to fertilizer runoff since plant uptake is not likely a major component with only 2% establishment (Appendix C). By the end of the third storm (4 in. of applied water) SRP was down to 0.47 $\frac{mg-P}{L}$ which was only 21% of the total P, where it remained for the majority of the remaining trial; at this point grass had 26% establishment (Appendix C).

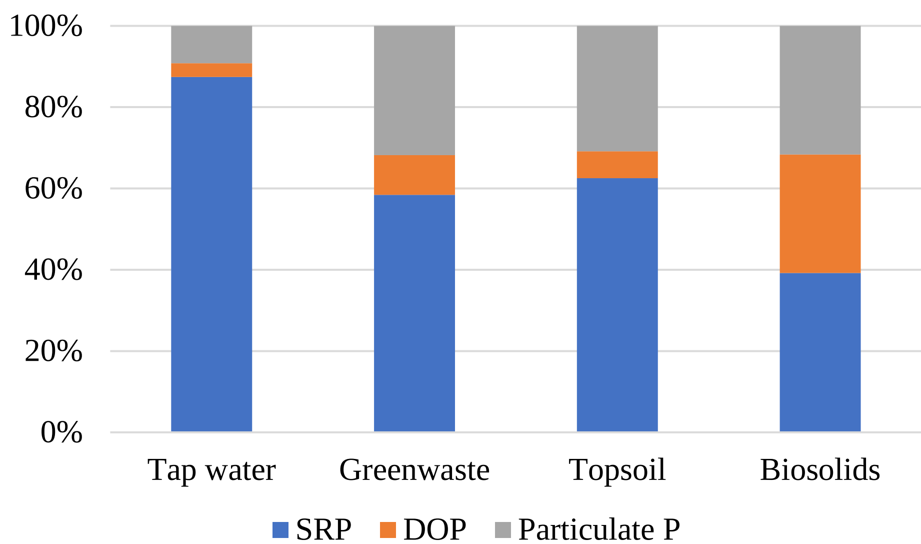


Figure 4-22: Average percent breakdown of the phosphorus species throughout the entire 2:1 trial.

In contrast to the reduction in SRP found in the topsoil effluent, greenwaste had increasing SRP percentages with decreasing particulate P; initial SRP was 38% of total P, 2.8 $\frac{mg-P}{L}$, which rose to 61% at 12 in., 1.2 $\frac{mg-P}{L}$, with a maximum of 81% SRP at 4 in. applied water, 4.1 $\frac{mg-P}{L}$. Particulate P began at 52% of total P, 3.7 $\frac{mg-P}{L}$, and dropped to 23%, 0.44 $\frac{mg-P}{L}$. Sediment values for the greenwaste at a 2:1 slope showed consistent reduction with applied water; this could account for the initial particulate P release.

Biosolids behaved similarly to topsoil; smaller particulate P release in the beginning, 12% of total P with particulate P concentration of 1.5 $\frac{mg-P}{L}$, with increased particulate P release at the end, 61% with particulate P concentration 0.89 $\frac{mg-P}{L}$. In both greenwaste and biosolids amended slopes, grass establishment was poor, maximum of 16% and 2% respectively (Table 4) which indicates that the majority of P released is due to P migration through runoff and infiltration than plant uptake.

Nitrogen species contributions were fairly similar for all soil media. There were initially higher organic N concentrations that reduced throughout the trial while either nitrate or ammonium composed the majority of the final released N. Initial and final organic N concentrations and percentages of total N were: 161 $\frac{mg-N}{L}$, 38%, and < 0.05 $\frac{mg-N}{L}$, < 1%; 54 $\frac{mg-N}{L}$, 73%, and 0.8 $\frac{mg-N}{L}$, 16%; and 43 $\frac{mg-N}{L}$, 46%, and 0.43 $\frac{mg-N}{L}$, 16%, for greenwaste, topsoil, and biosolids, respectively. On average, greenwaste and topsoil runoff were comprised mostly of nitrate, 77% and 45% respectively, while the biosolids effluent was largely ammonium, 52% (Figure 4-23).

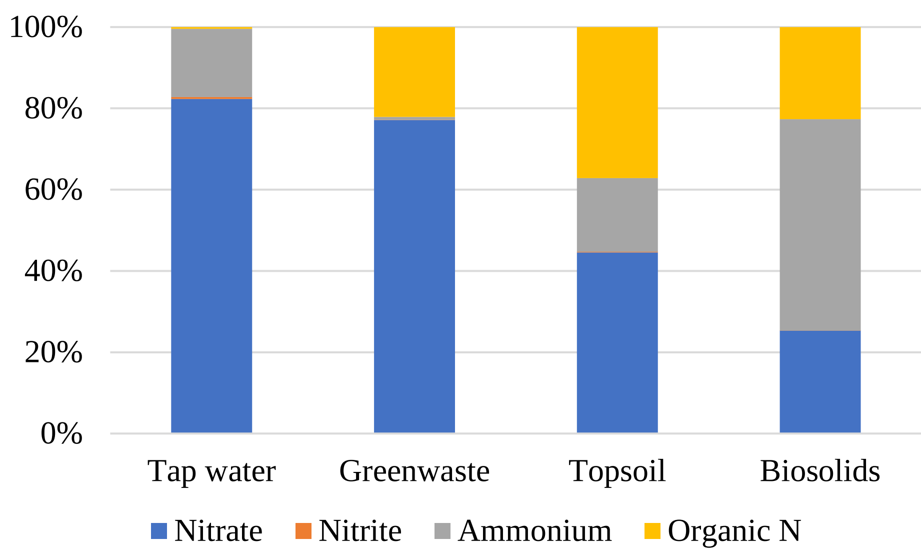


Figure 4-23: Average percent breakdown of nitrogen species. Nitrite was consistently below 1% for all soil media.

Throughout the trial, most of the total N from greenwaste effluent was nitrate. As the percentage of organic N declined throughout the trial, nitrate increased from 61% to 98% of total N, 254 $\frac{mg-N}{L}$ to 7.5 $\frac{mg-N}{L}$ of the total N, 420 $\frac{mg-N}{L}$ and 7.6 $\frac{mg-N}{L}$, respectively. Ammonium remained between 1-2% throughout the trial, with a maximum concentration of 7.7 $\frac{mg-N}{L}$. Similarly, the percentage of organic N in topsoil was also replaced by nitrate as the trial progressed (with an increase in nitrate from 7% to 68%), with ammonium remaining between 6-35%. The nitrogen composition of biosolids was slightly different, organic N still reduced to 16% composition, but this was replaced largely by 54% ammonium at the end of the trial with a maximum of 78% at 9 in., 70 $\frac{mg-N}{L}$.

Total Mass Transport

Total effluent volumes for all greenhouse applications were collected for each storm. Using the concentrations and volumes presented earlier, the total mass of nutrients and sediments was then calculated after 12 in. of applied water. Due to the nature of how water quality samples were collected in the field (first flush samples without total volume of runoff measurements), it was not possible to compute total nutrient mass transport. However, sediment runoff samples were collected independently of runoff volume and accumulated sediment transport can be compared (Figure 4-24).

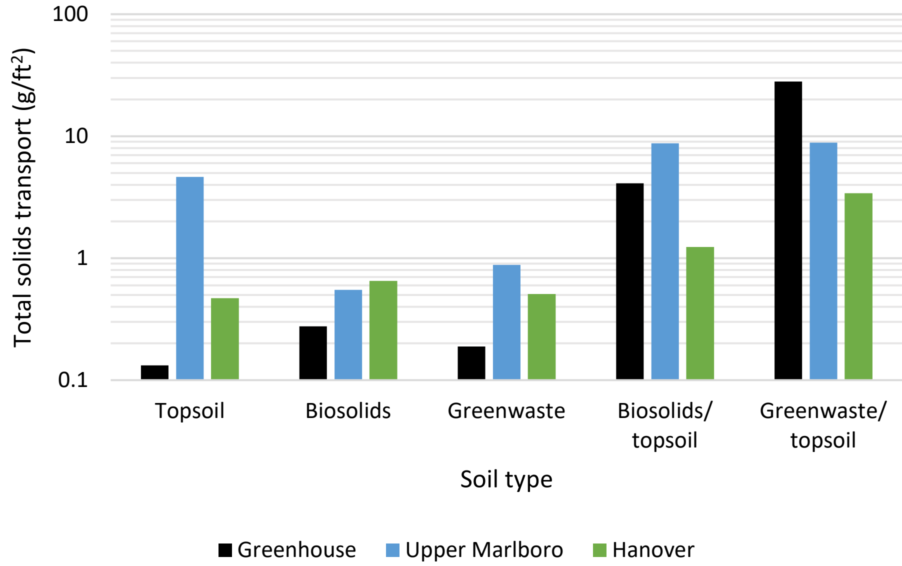


Figure 4-24: Total sediment loss after approximately 12 in. of rainfall and applied water for all medium applications in the greenhouse and at each field site.

The calculated totals in Figure 4-24 correspond to the mass transported per squared foot. Each greenhouse plot and the Upper Marlboro site received 12 in. of rainfall while Hanover received 13 in. Upper Marlboro had statistically greater mass transport of nutrients than Hanover, ranging from 0.5 $\frac{g}{ft^2}$ for biosolids runoff to 8.9 $\frac{g}{ft^2}$ for greenwaste/topsoil. Except for the greenwaste/topsoil (28 $\frac{g}{ft^2}$) and biosolids/topsoil (4.1 $\frac{g}{ft^2}$) media, the greenhouse study had lower total sediment mass transport among the three locations, with topsoil releasing the least at 0.13 $\frac{g}{ft^2}$.

Both biosolids and greenwaste applications consistently produced higher nutrient concentrations than topsoil and compost/topsoil blends, as discussed earlier. However, these two applications had significantly lower runoff volumes than compost/topsoil blends. The maximum effluent volumes for biosolids and greenwaste at the 4:1 slope were 1.1 L and 2.6 L with minimums of 0.21 L and 0.23 L, respectively. Greenwaste/topsoil and biosolids/topsoil produced maxima of 33 L and 24 L with minima of 1.0 L and 0.02 L. These differences in effluent volumes and concentrations balanced out and resulted in more comparable mass transport results (Figure 4-25).

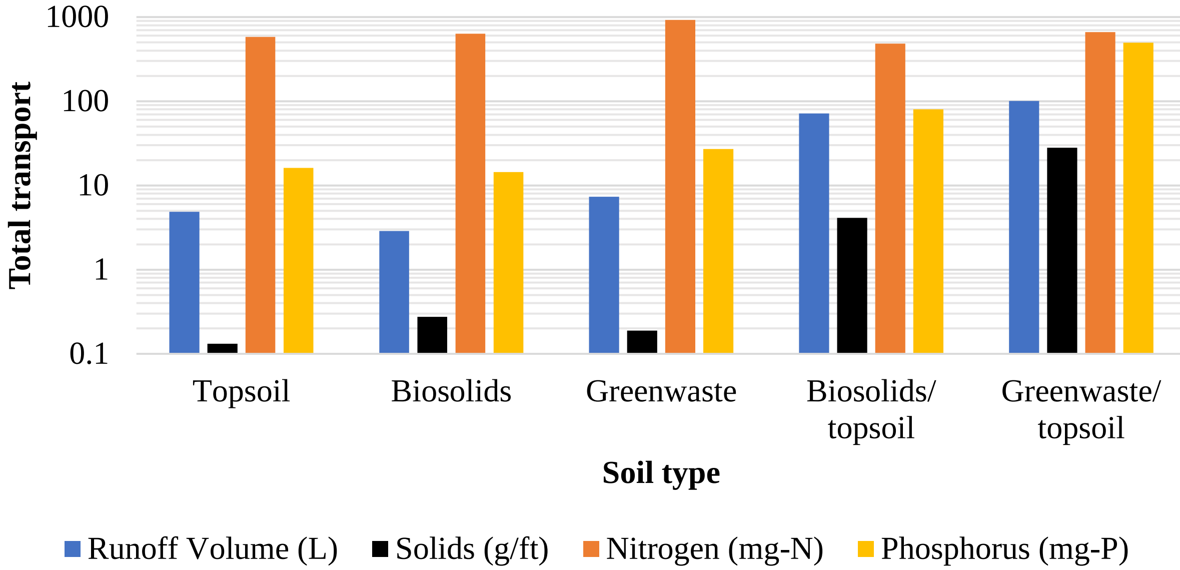


Figure 4-25: Total mass of transported nutrients and sediment for all medium applications at the 4:1 slope after 12 in. of applied water. The vertical axis is on the log scale to help visualize the data.

After the inclusion of effluent volume with concentration, the total mass of P, over the course of the 12 in. of applied water, was greatest in the greenwaste/topsoil application with 498 mg-P while biosolids had the least with 14 mg-P. The total mass of N released was greatest in pure greenwaste with 925 mg-N and least in biosolids/topsoil with 484 mg-N. These results indicate that topsoil addition improved the nitrogen release for biosolids while producing an increased mass of phosphorus. Topsoil alone produced values in between without lower or higher concentrations of P or N but did have the lowest sediment transport, 4.9 mg-solids/ft.

As mentioned previously, the lowest concentrations and volumes were measured for biosolids, topsoil, and greenwaste at the 20:1 slope. As a result, the total mass of transported nutrients and sediments was also reduced (Figure 4-26). Here greenwaste produced the most runoff and highest sediment and nutrient loss; 8.6 L, 1.5 g-solids/ft, 14 mg-P, and 185 mg-N. Biosolids produced a total of 0.1 L of runoff and sediment loss could not be measured.

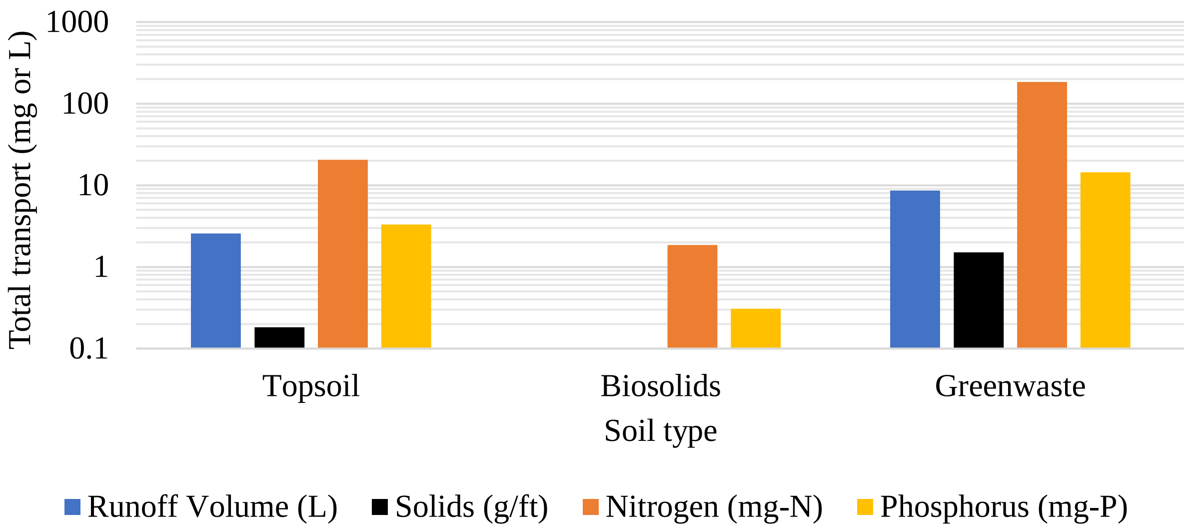


Figure 4-26: Nutrient, sediment, and runoff volume for biosolids, greenwaste, and topsoil at the 20:1 slope. Biosolids only had 0.1 L of total runoff volume and does not have any measured sediment loss resulting in no visible transport of sediment.

At the 2:1 slope biosolids again had the lowest runoff volume, which resulted in much lower mass transport of P, N and sediment despite higher concentrations (Figure 4-27). Greenwaste produced the most N at this slope angle with 2756 mg-N, but topsoil ultimately had more sediment and P release, 25 g-solids and 115 mg-P.

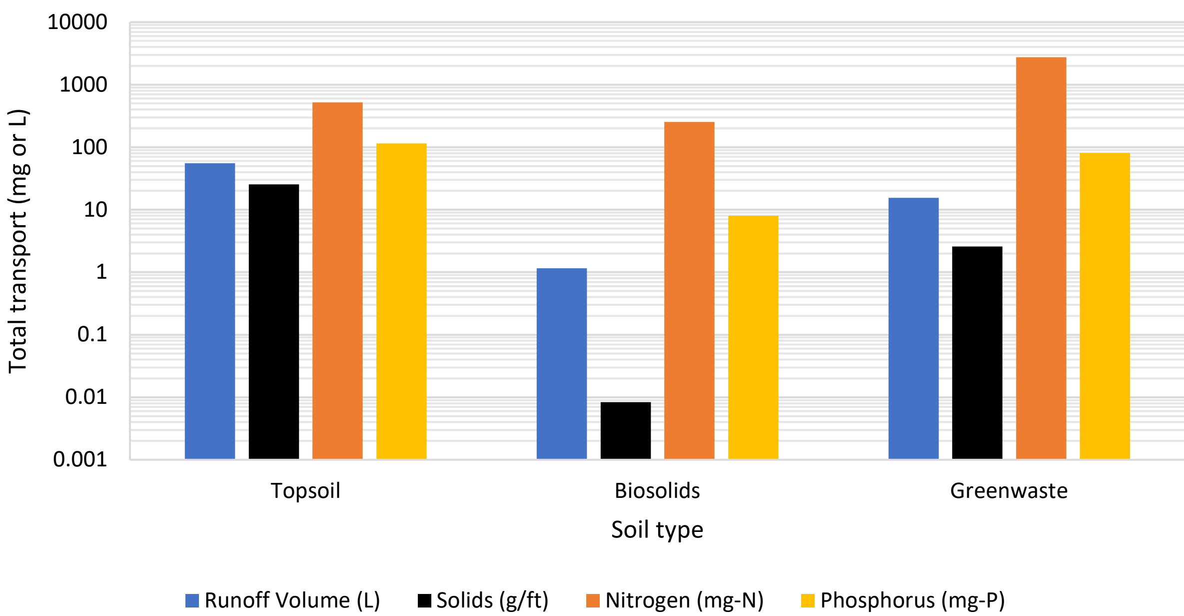


Figure 4-27: The total transport of sediments and nutrients for the 2:1 slope after 12 in. of applied water.

5. Conclusions

Three observed growth periods were seen in the field element of this project. The field growth studies showed few significant differences between the different soil medium applications. Only biosolids (72% versus 37-60% at 90 days), at the Hanover site, and topsoil (81% versus 60-69% at 87 days) at the Upper Marlboro site had significantly higher initial grass establishment than the other applications, and none were significantly different after the first phase of growth. Grass establishment in the greenhouse focused only on the initial phase of establishment. At a 20:1 slope, biosolids, topsoil, and greenwaste growth were all statistically similar (91%, 70%, and 94% establishment at 70 days). At increased slope, 4:1 and 2:1, both biosolids and greenwaste, failed to grow above 16% establishment. Both biosolids/topsoil and greenwaste/topsoil had 31% grass establishment after 12 in. of rainfall. This growth was slightly higher than topsoil at 22% establishment, despite the lack of straw coverage.

All medium applications reduced the volume of water applied to the surface. Biosolids was the most effective at volume reduction and outperformed the current MDOT SHA standard by 40-98%. The compost/topsoil mixtures produced the most runoff volume when compared to all other media and produced 14-25 times the volume of runoff compared to MDOT SHA standard topsoil.

Sediment transport was the greatest at the Upper Marlboro site. Although not statistically significant, after 12 in. of rainfall, the cumulative mass of both greenwaste/topsoil and biosolids/topsoil blends appeared to have lost more sediment than other medium applications at both field sites, $3.4\,\frac{g}{ft^2}$ and $1.2\,\frac{g}{ft^2}$ at Hanover and $8.9\,\frac{g}{ft^2}$ and $8.8\,\frac{g}{ft^2}$ at Upper Marlboro. Greenhouse observations agreed with the field results with both compost/topsoil blends losing more sediment, but only the greenwaste/topsoil blend was statistically greater on a g/ft^2 basis. Loss of sediment did not seem to be associated with rainfall, however, and larger storms seen in the field produced larger quantities of sediment for all media.

Greenhouse media studies showed that topsoil application as well as topsoil/compost blends tended to produce lower concentrations of P and N than pure compost application at 4:1 and 2:1 slopes. TP and TN values were between $1.4 - 18\,\frac{mg-P}{L}$ and $108 - 186\,\frac{mg-N}{L}$, $1.7 - 5.3\,\frac{mg-P}{L}$ and $4.8 - 25\,\frac{mg-N}{L}$ and $3.0 - 7.5\,\frac{mg-P}{L}$ and $2.4 - 47\,\frac{mg-N}{L}$ for topsoil, biosolids/topsoil, and greenwaste/topsoil, respectively, versus $1.8 - 7.2\,\frac{mg-P}{L}$ and $38 - 230\,\frac{mg-N}{L}$ and $5.8 - 7.6\,\frac{mg-P}{L}$ and $101 - 480\,\frac{mg-N}{L}$ for greenwaste and biosolids, respectively. The extraction data collected for all five soil media showed a similar trend with both composts having the most P and N, topsoil having the least, and the mixtures typically in between. This trend was not as evident in the field site samples. Topsoil P and N concentrations were only statistically lower when compared to biosolids and the topsoil/greenwaste mixture, but other media runoff concentrations were typically measured as not statistically different to the topsoil application depending on the location and type of nutrient.

On average over the 12 in. of applied water during greenhouse studies, the major species of P and N released were SRP and nitrate for greenwaste (58% of TP and 77% of TN) and topsoil (62% of TP and 45% of TN); biosolids produced large percentages of SRP and ammonium (39% of TP and 52% of TN). Through the course of the study, both topsoil and biosolids released a larger percentage of TP as particulate P as water was applied (from 12-61% and 16-57%, respectively), while greenwaste produced more SRP (from 38-61% of TP). Effluent TN as organic N decreased for all medium applications with applied water (38-<1%, 73-16%, and 46-16% of TN for grenwaste, topsoil, and biosolids respectively). As water was applied, both greenwaste and topsoil released more nitrogen as nitrate (final 97% and 68% of TN) while biosolids released more TN as ammonium (final 50% of TN).

In calculating total mass of transported nutrients after 12 in. of applied water, the total mass of P leached was the greatest in the greenwaste/topsoil application with 498 mg-P while biosolids was the least with 14 mg-P. The total mass of N released was the greatest in pure greenwaste with 925 mg-N and the least in biosolids/topsoil with 484 mg-N.

According to both field and greenhouse observations, pure compost addition has the potential to greatly reduce the overall runoff volume. However, this compost is highly rich in nutrients and was seen to leach both P and N at higher concentrations than the current practices. Mixing compost with topsoil produced a media with less total nutrients that produced far lower leachate concentrations but had far greater runoff volume.

MDOT SHA RECOMMENDATIONS

For shallow slopes (20:1), compost use is advisable, the improved infiltration reduces runoff and the compost provides ample nutrients for grass growth. At slopes of 4:1 or greater, uncovered pure compost or compost/topsoil blends should not be used as this results in large nutrient and volume runoff.

RECOMMENDATIONS FOR FURTHER RESEARCH

It is necessary to observe additional ratios of compost/topsoil blends with straw cover. The addition of straw will reduce soil sealing and promote increased infiltration while also protecting the soil from drying out. This will likely produce lower concentrations of nutrient loss as well as lower total runoff volume.

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7. Appendices

Appendix A: Analysis chemicals, filters, and equations

Test	Chemical	Formula	C.A.S No.	Company	Assay
TP, SRP	Ammonium molybdate tetrahydrate	$(NH_4)_6Mo_7O_{24}$* $4H_2O$	12054-85-2	Acros Organics	99+%
TP, SRP	Potassium antimonal tartrate trihydrate	$C_8H_4K_2O_{12}Sb_2$* $3H_2O$	28300-74-5	Acros Organics	99+%
TP, SRP	Ascorbic acid	$C_6H_8O_6$	50-81-7	Acros Organics	ACS grade
TP, SRP	Sulfuric acid	H_2SO_4	7664-93-9	VWR chemicals	95-98
TP	Potassium persulfate	$K_2S_2O_8$	7727-21-1	Acros Organics	99+%
TP	Phenolphthalein	$C_{20}H_{14}O_4$		Fisher Chemical	ACS grade
TP, NO2	Sodium hydroxide	NaOH	1310-73-2	Fisher Chemical	98.7%
TP, SRP, DP	Phosphate standard	PO_4	LC18570	Lab Chem™	Certified
TN, NO3	Nitrogen standard	NO_3	LC17900	Lab Chem™	Certified
NO2	N - (1-napthyl) - Ethylenediamine dihydrochloride	$C_{12}H_{14}N_2$*2HCl	1465-25-4	Alfa Aesar	ACS grade
NO2	Phosphoric Acid	H_3PO_4	7664-38-2	Fisher Chemical	85%
NO2	Sodium Nitrite	$NaNO_2$	7632-00-0	Fisher Chemical	ACS grade
NO2	Sulfanilamide	$C_6H_8N_2O_2S$	63-74-1	Fisher Chemical	98.9%
NH4	Ammonium chloride, anhydrous	NH_4Cl	12125-02-9	Fisher Chemical	ACS grade
NH4	EDTA disodium salt dihydrate	$C_{10}H_{14}N_2Na_2O_8$ * $2H_2O$	6381-92-6	Fisher Chemical	ACS grade
NH4	Phenol, crystalline	C_6H_5OH	108-95-2	Fisher Chemical	ACS grade
NH4	Sodium nitroferricyanide dihydrate	$Na_2\{Fe(CN)_5NO\}$ * $2H_2O$	13755-38-9	Fisher Chemical	ACS grade
TSS	Glass fibre filters			MilliporeSigma™	
DP, SRP, NO3, NO2, NH4	Mixed Cellulose Ester Membranes: 0.22 um			MilliporeSigma™ MF-™	

Equation 1: Image normalization.

```
I = imread(image); A = im2double(I);
R = A(:,:,1); G = A(:,:,2); B = A(:,:,3);
r = R./(R+G+B);
g = G./(R+G+B);
b = B./(R+G+B);
```

Equation 2: Particulate phosphorus

$$Particulate\ P = TP - DP;$$

Equation 3: Dissolved organic phosphorus

$$Dissolved\ organic\ P = DP - SRP;$$

Equation 4: Organic nitrogen

$$Organic\ N = TN - ([NO_3^- - N] + [NO_2^- - N] + [NH_3 - N])$$

Equation 5: Mann-Kendall trend test

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

$$\xi = \begin{cases} \frac{S-1}{v^{0.5}}; for\ S > 0 \\ 0; for\ S = 0 \\ \frac{S+1}{v^{0.5}}; for\ S < 0 \end{cases} ; \xi\ is\ the\ normal\ distribution\ N(0,1)$$

$$v = \frac{n(n-1)(2n+5) - \sum_{i=1}^{g} t_i(t_i-1)(2t_i+5)}{18}; \begin{matrix} g\ is\ the\ number\ of\ ties \\ t\ is\ the\ number\ of\ groups\ of\ ties \end{matrix}$$

Equation 6: Student's t-test with equal variance:

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$s_p = \sqrt{\frac{(n_1 - 1)s_{X_1}^2 + (n_2 - 1)s_{X_2}^2}{n_1 + n_2 - 2}}$$

Equation 7: Welch's t-test with unequal variances:

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_{\overline{\Delta}}}$$

$$s_{\overline{\Delta}} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

Equation 8: Modified thompson tau test

$$n = number\ of\ points;\ \overline{x_i} = is\ the\ mean\ of\ the\ current\ set\ of\ points\ being\ tested$$

$$\delta_i = |x_i - \overline{x}|$$

$$\tau = \frac{t_{\alpha/2} * (n-1)}{\sqrt{n} * \sqrt{n - 2 + t_{\alpha/2}^2}}$$

APPENDIX B: SITE CONSTRUCTION

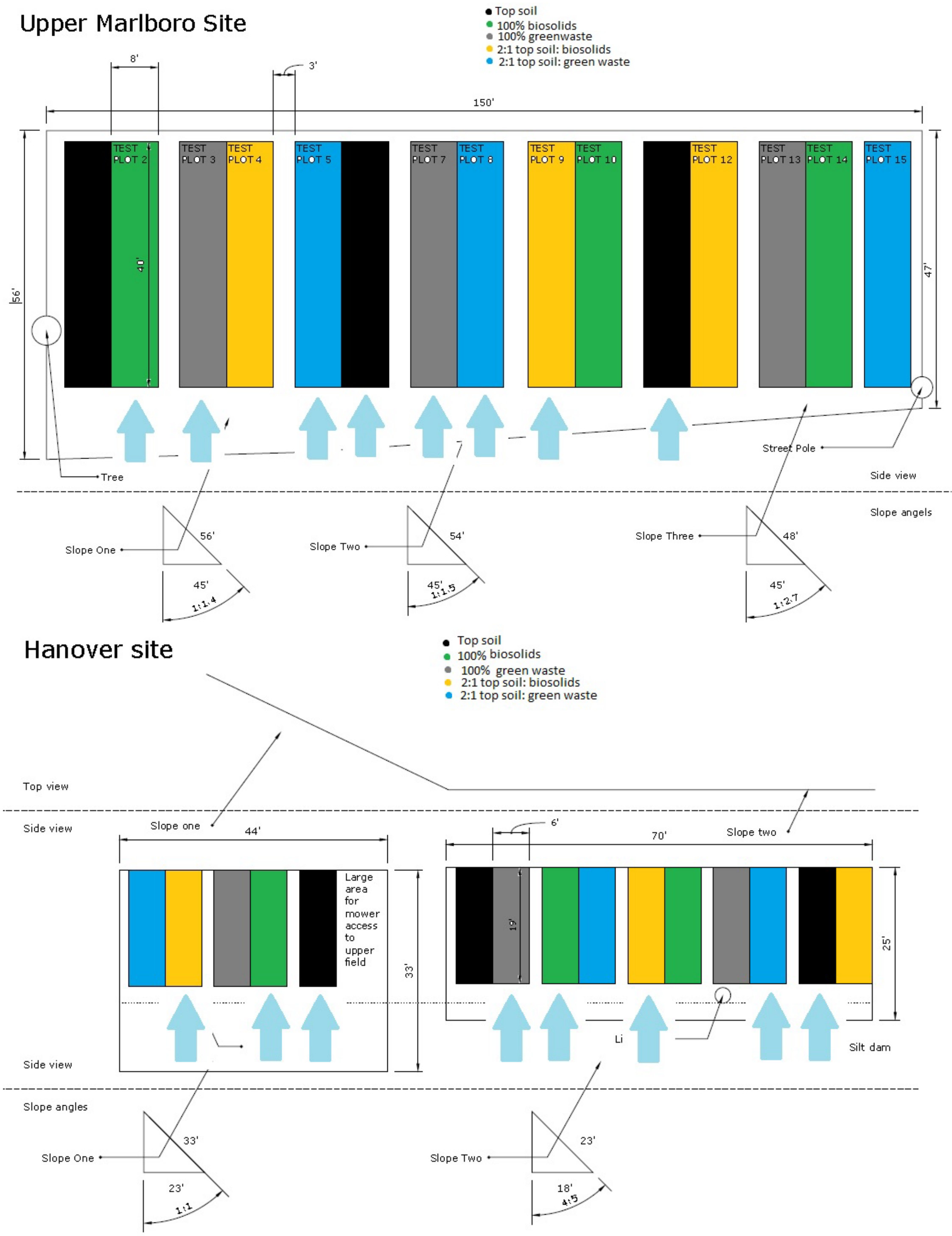
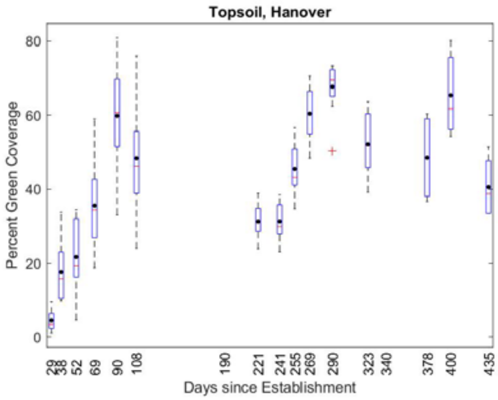
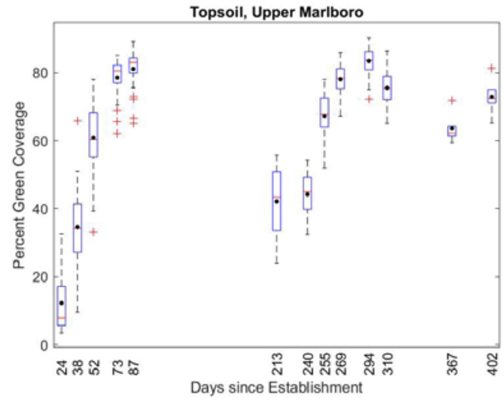
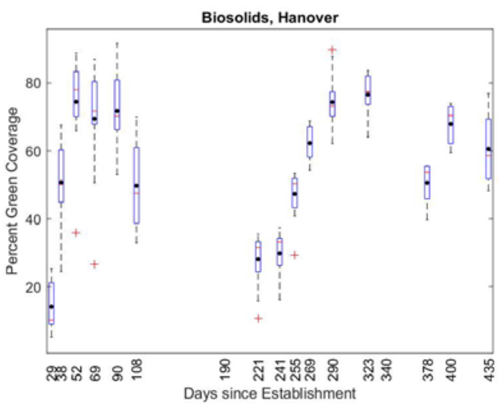


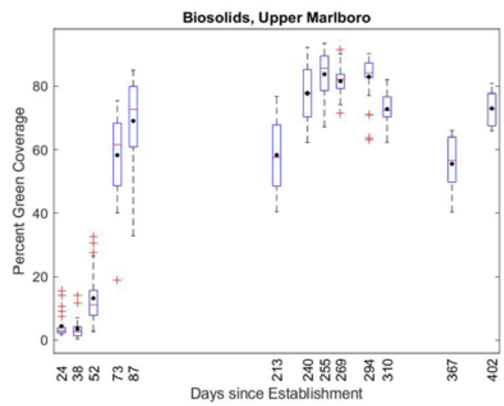
Figure 7-1: Upper Marlboro and Hanover site designs. Blue arrows indicate locations for water runoff sampling bottles.

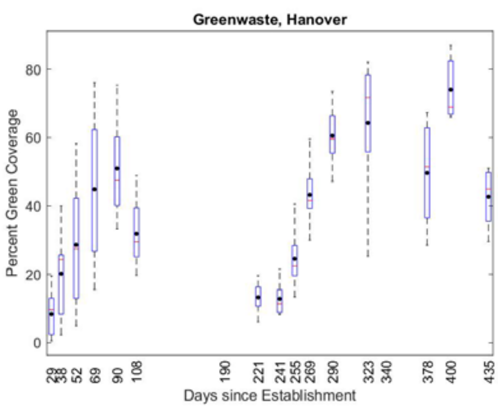
APPENDIX C: GRASS COVERAGE

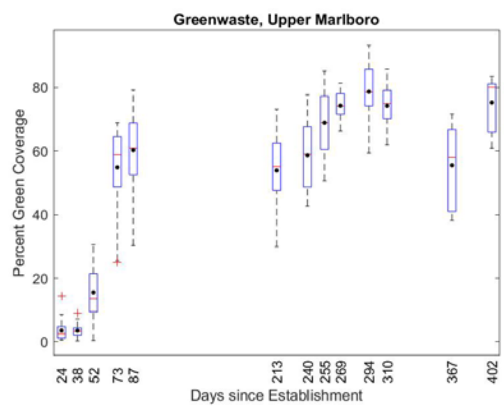












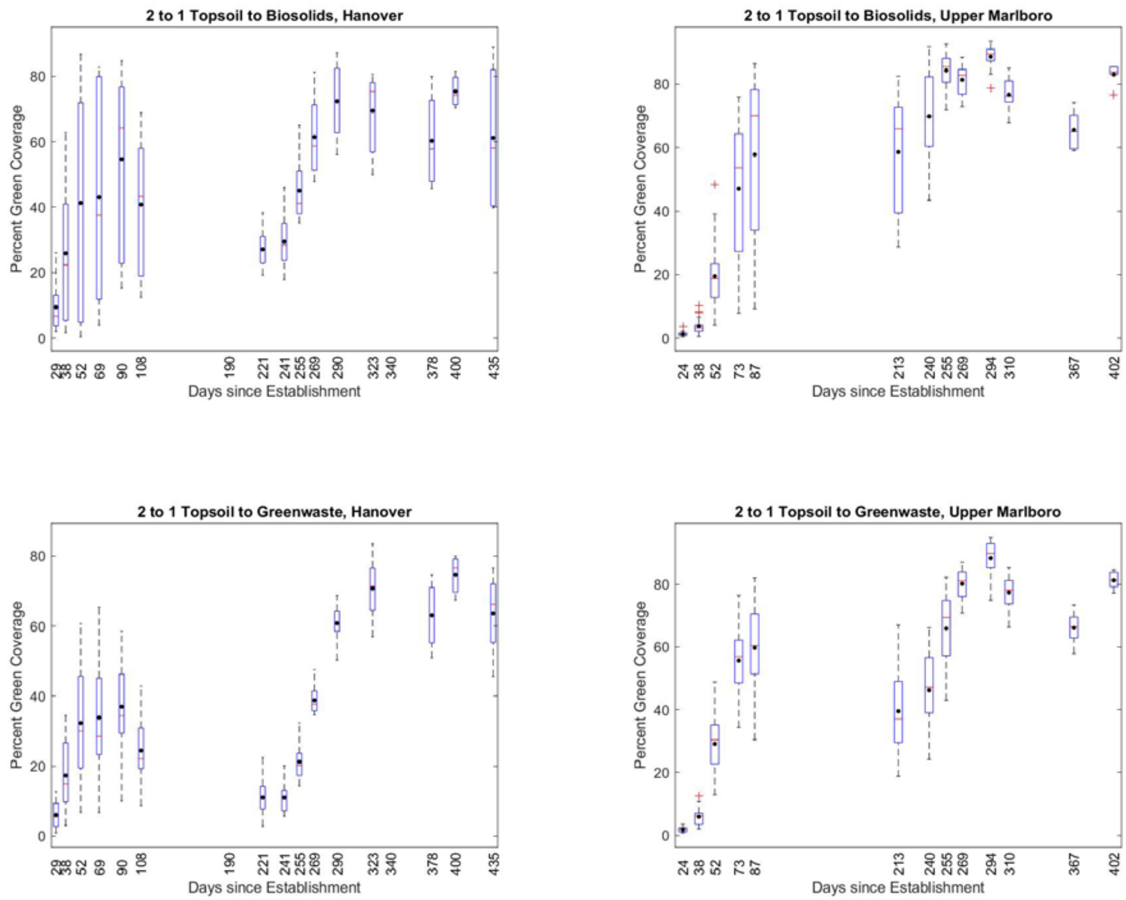
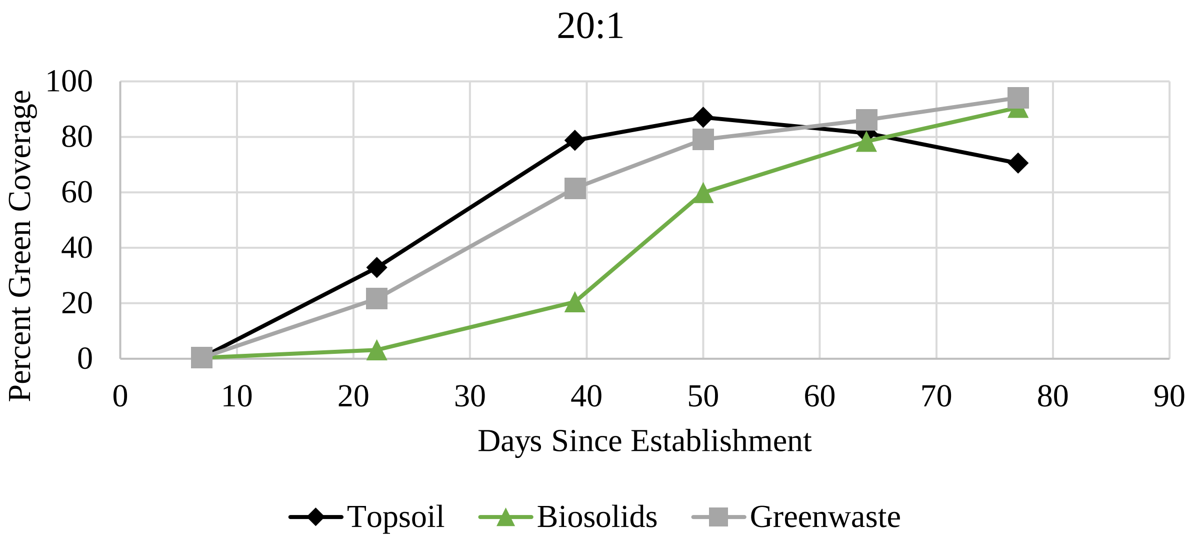
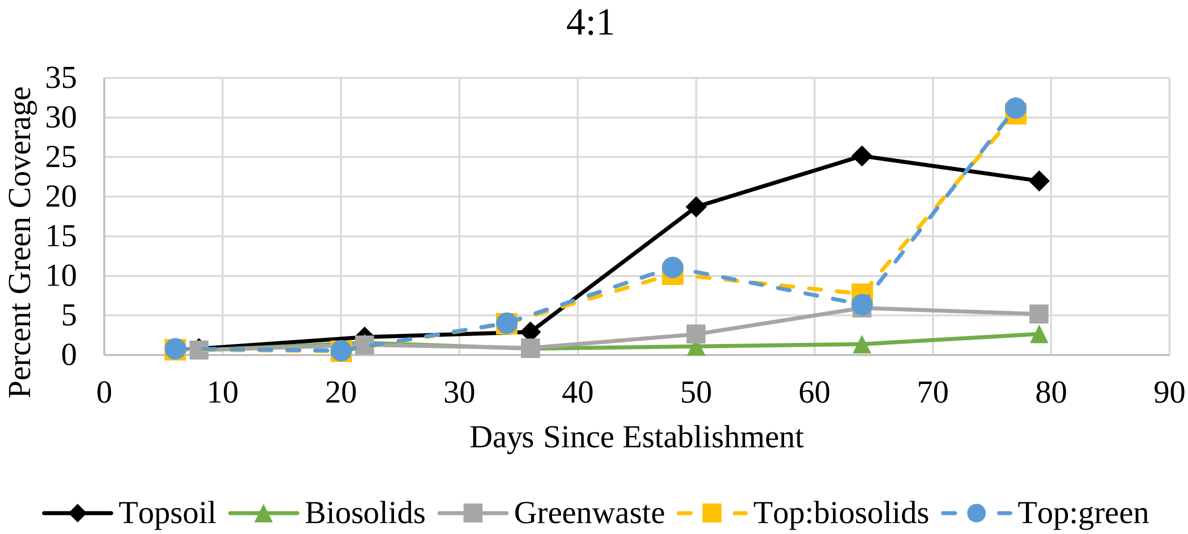


Figure 7-2: Range of grass growth for all media types at both Hanover and Upper Marlboro.


20:1
Percent Green Coverage
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
Days Since Establishment
Topsoil
Biosolids
Greenwaste


4:1
Percent Green Coverage
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
Days Since Establishment
Topsoil
Biosolids
Greenwaste
Top:biosolids
Top:green

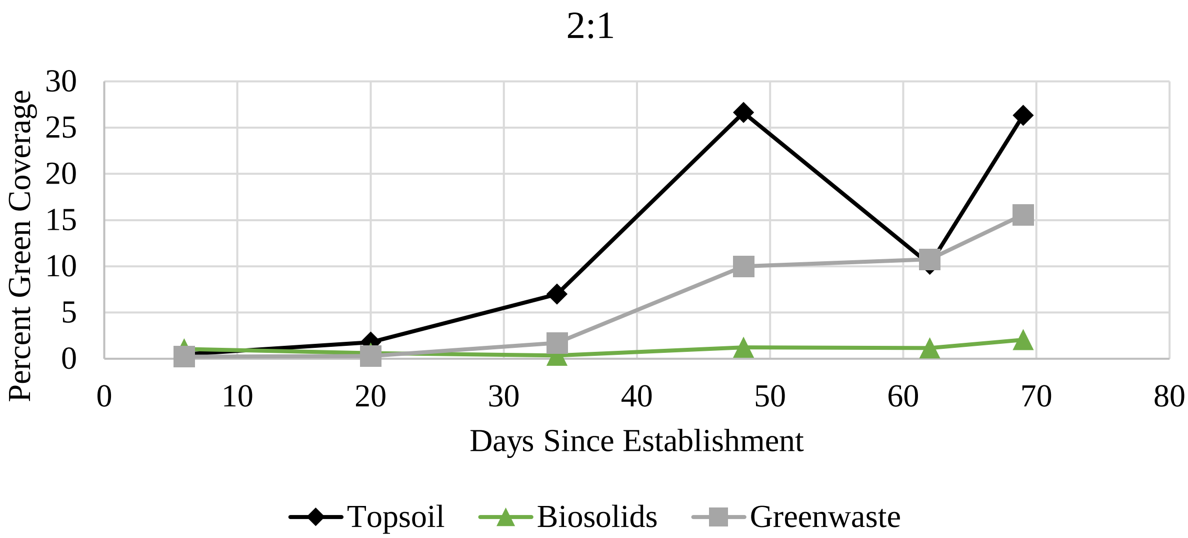
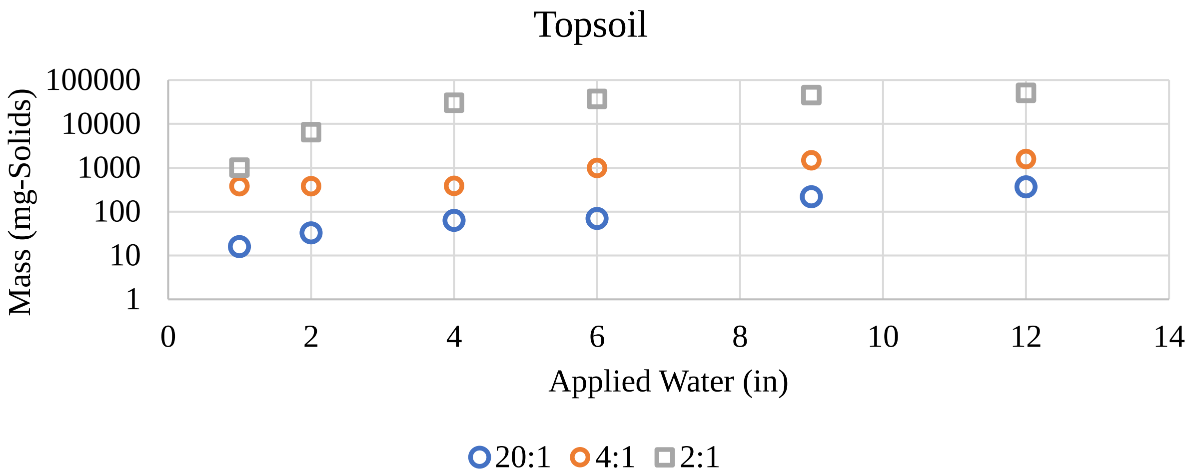
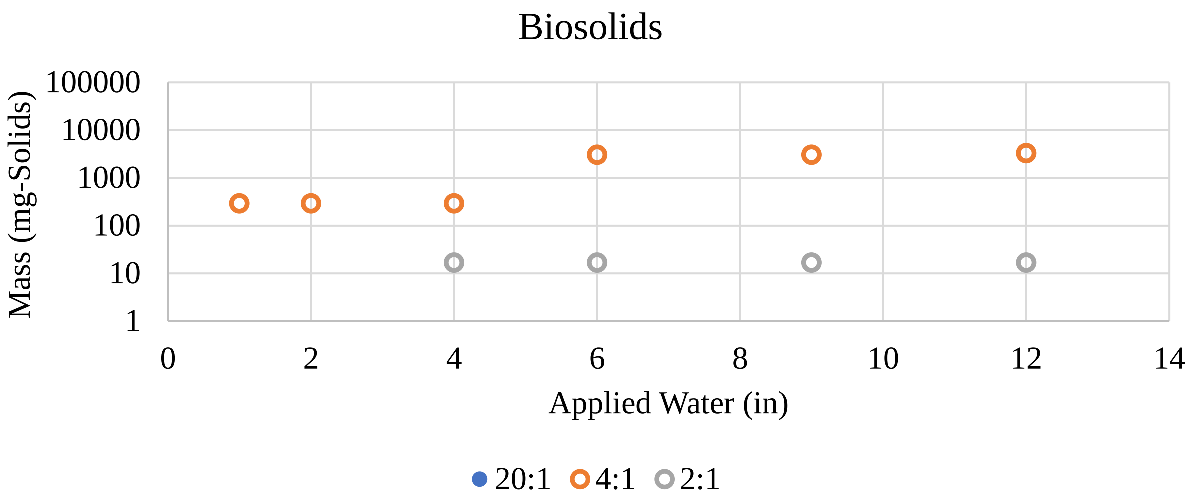


Figure 7-3: Green cover for the greenhouse studies.

APPENDIX D: SEDIMENT LOSS





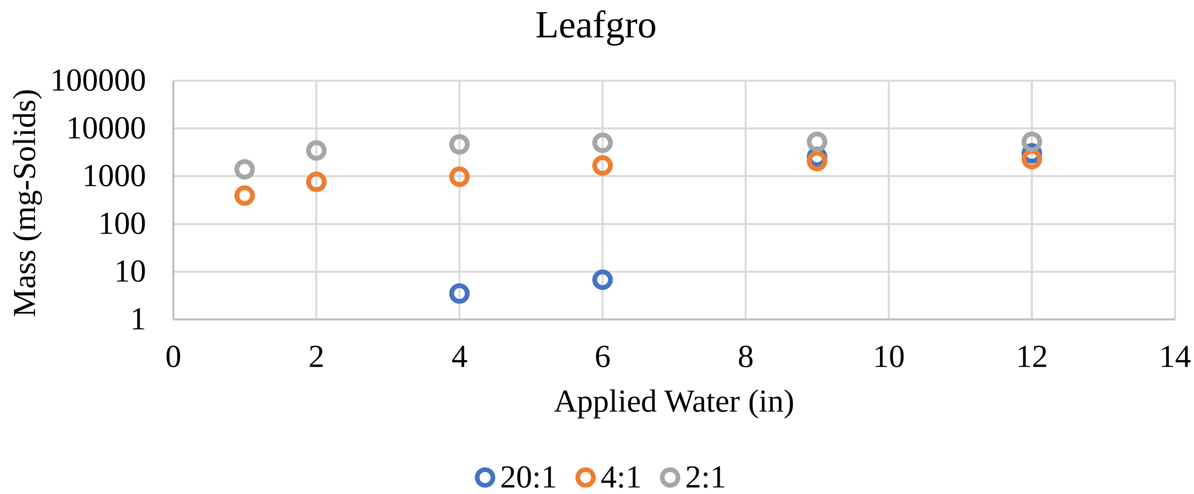


Figure 7-4: Sediment mass transport based on EMC and volume values for topsoil and both pure composts at 20:1, 4:1 and 2:1 slopes. All vertical axis are on a logarithmic scale.

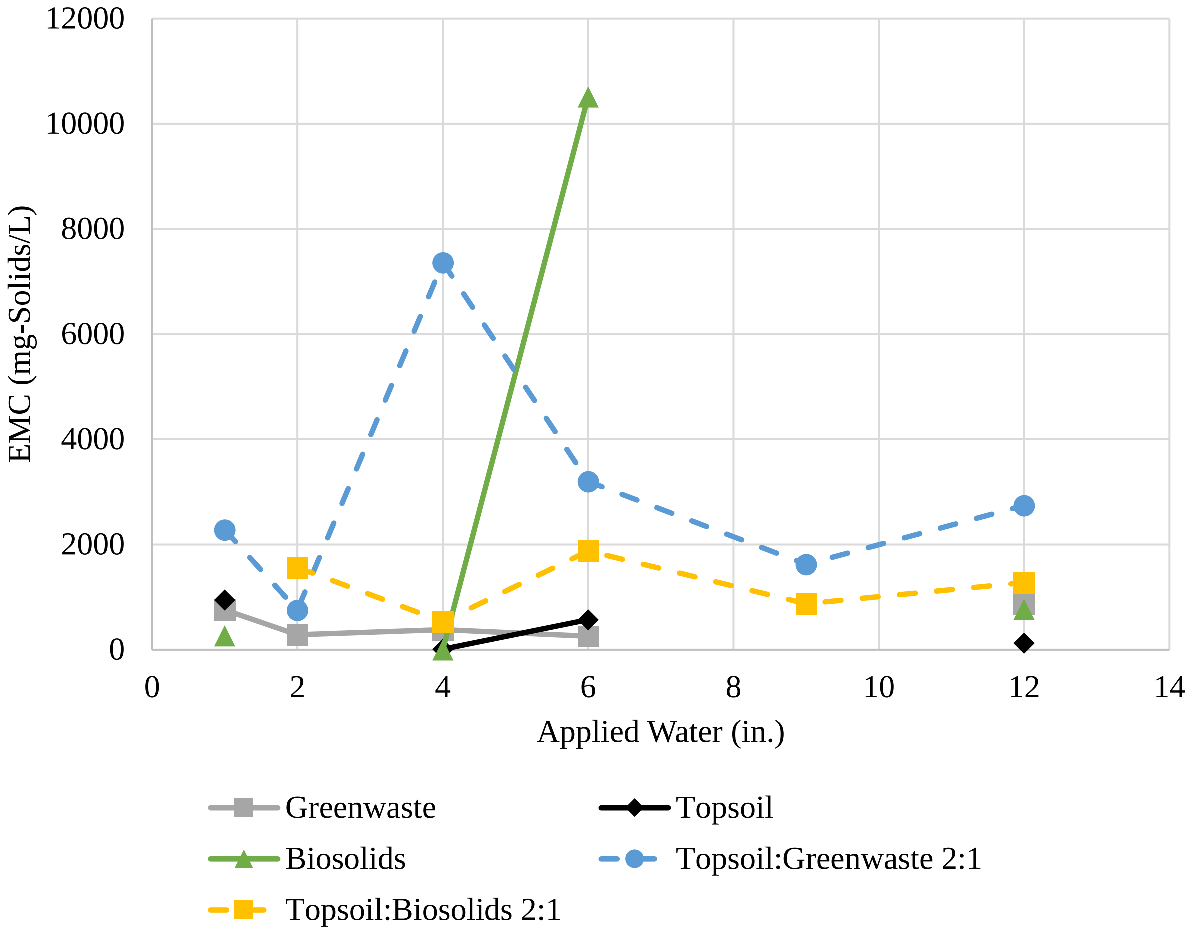


Figure 7-5: EMC for solids for all medium applications at the 4:1 slope.

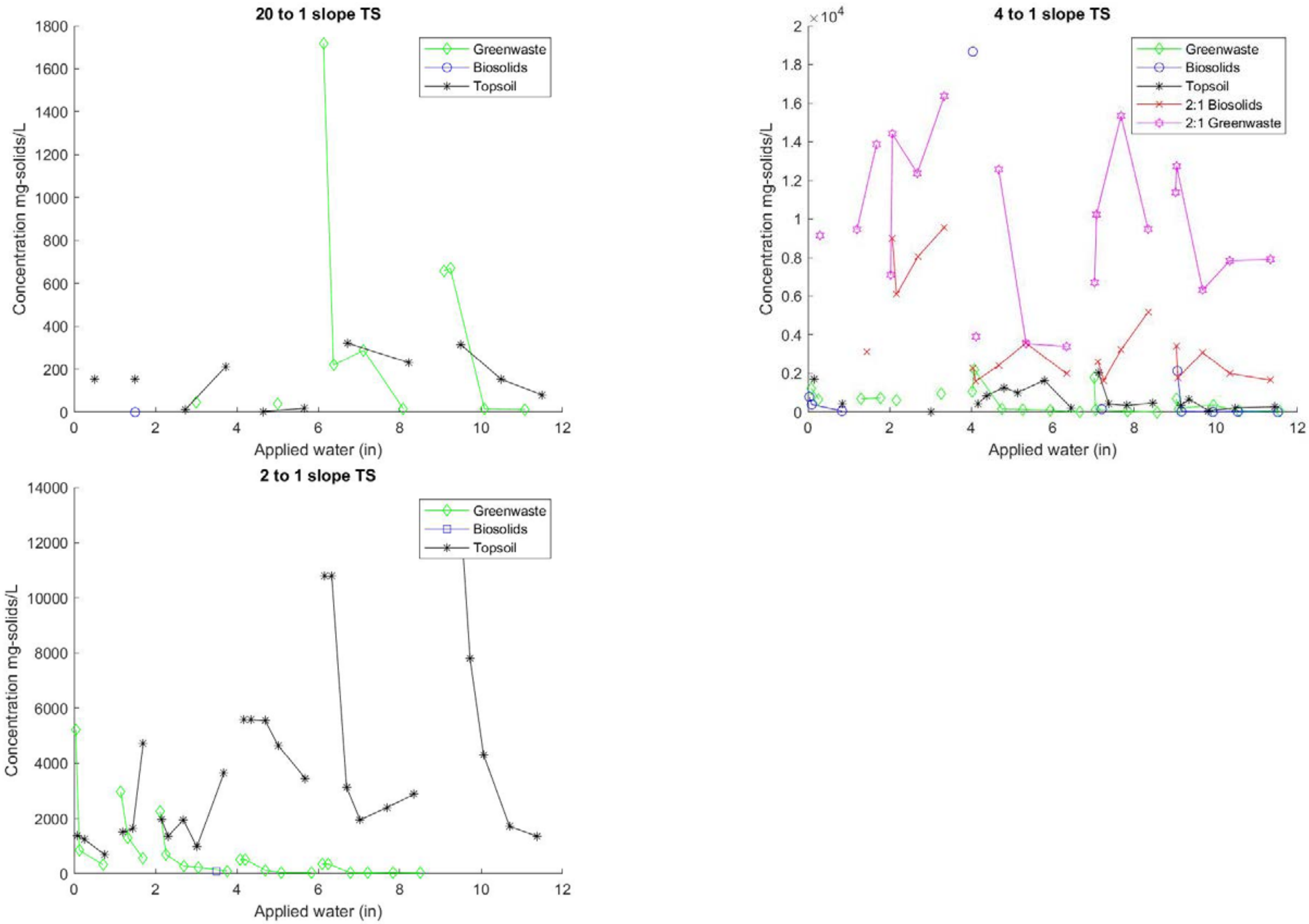


Figure 7-6: Effluent solids concentrations at all slope angles. All points represent grab samples taken immediately after sample collection for nutrient analysis. Only the 2:1 greenwaste shows a definite sediment reduction with applied water. The biosolids at all slope angles consistently produced very little sediment, but in one instance during the 4:1 slope trial a very large mass of sediment was dislodged from the slope to produce one spike in that data set.

APPENDIX E: NUTRIENT LEACHATE

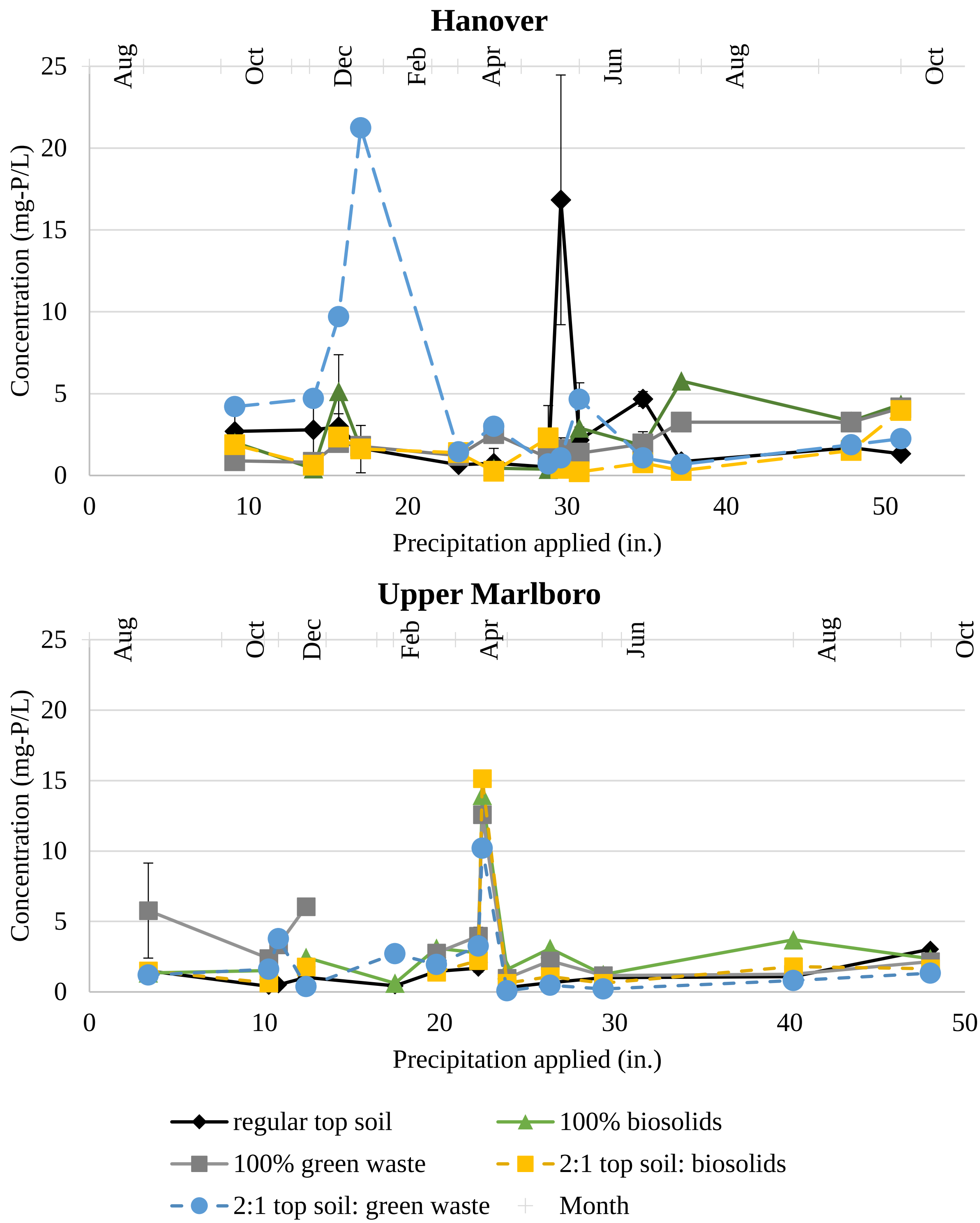
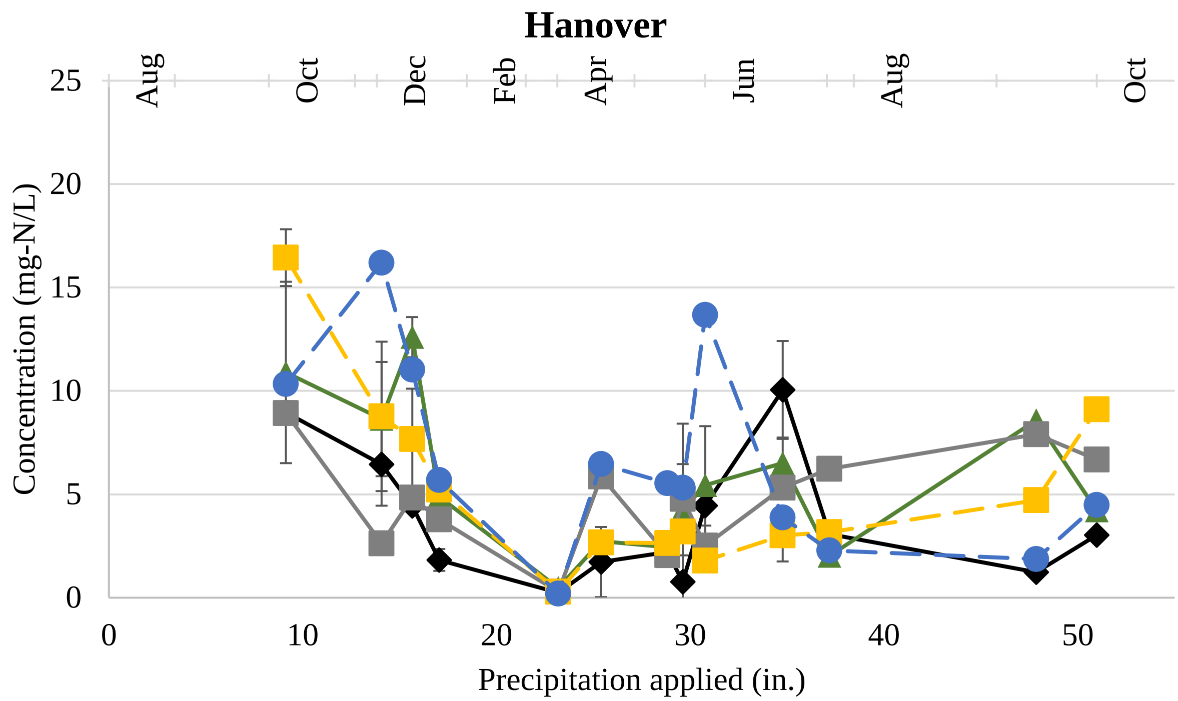


Figure 7-7: Phosphorus concentrations for both Upper Marlboro and Hanover field sites. There is no trend in the data for any of the media at either site which indicates that concentrations have reached a steady state of phosphorus leaching.



Hanover
Aug
Oct
Dec
Feb
Apr
Jun
Aug
Oct
25
20
15
10
5
0
Concentration (mg-N/L)
0
10
20
30
40
50
Precipitation applied (in.)

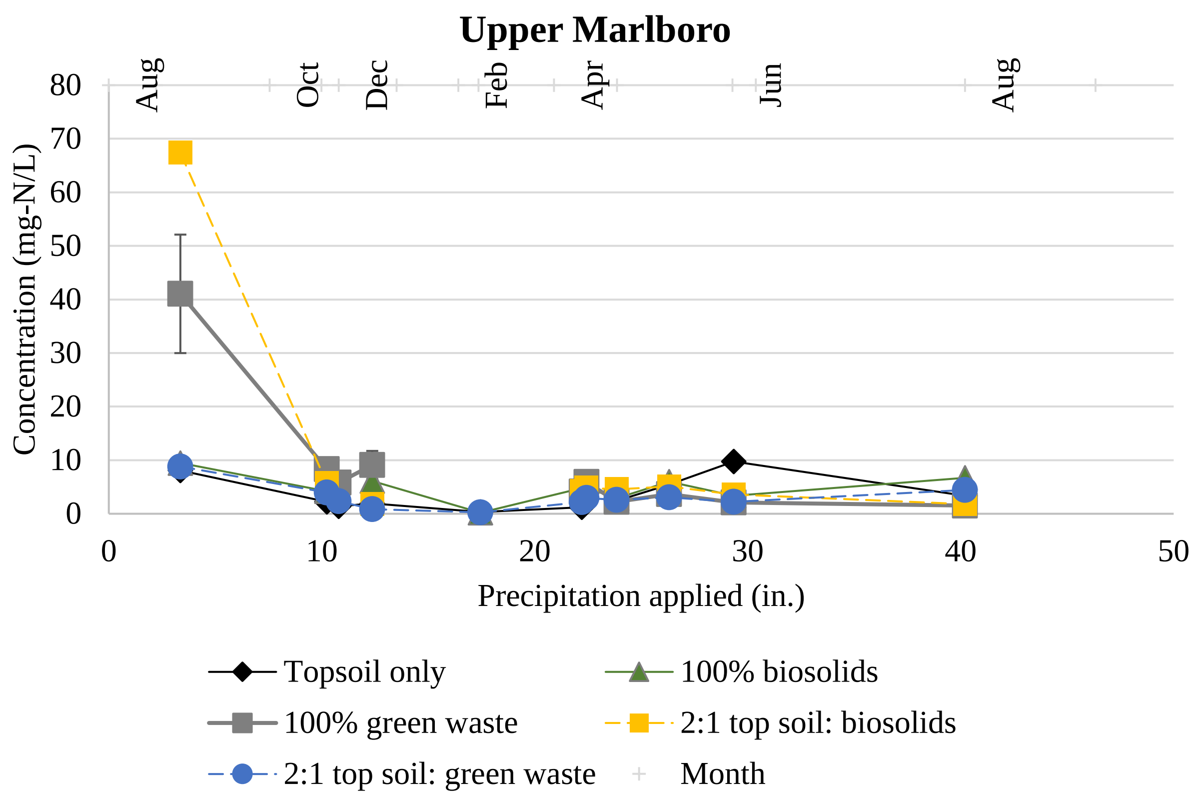
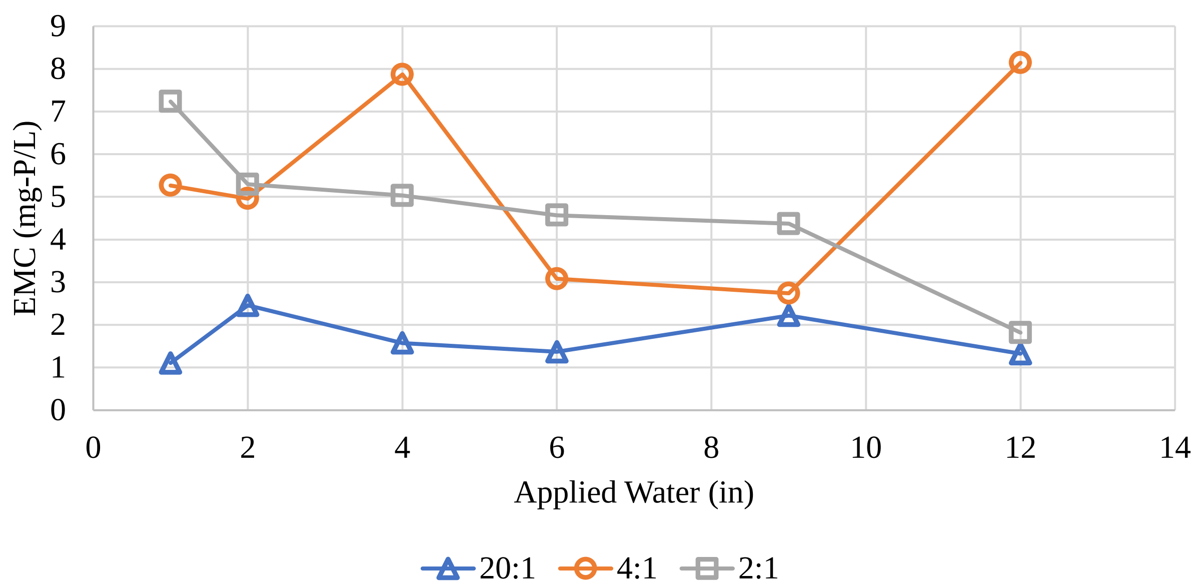


Figure 7-8: Nitrogen concentrations for the Hanover and Upper Marlboro sites. There are initially high concentrations found for both the 2:1 biosolids: topsoil and the greenwaste amendments at Upper Marlboro followed by more stable concentrations. This suggests a similar flush seen in the greenhouse studies.



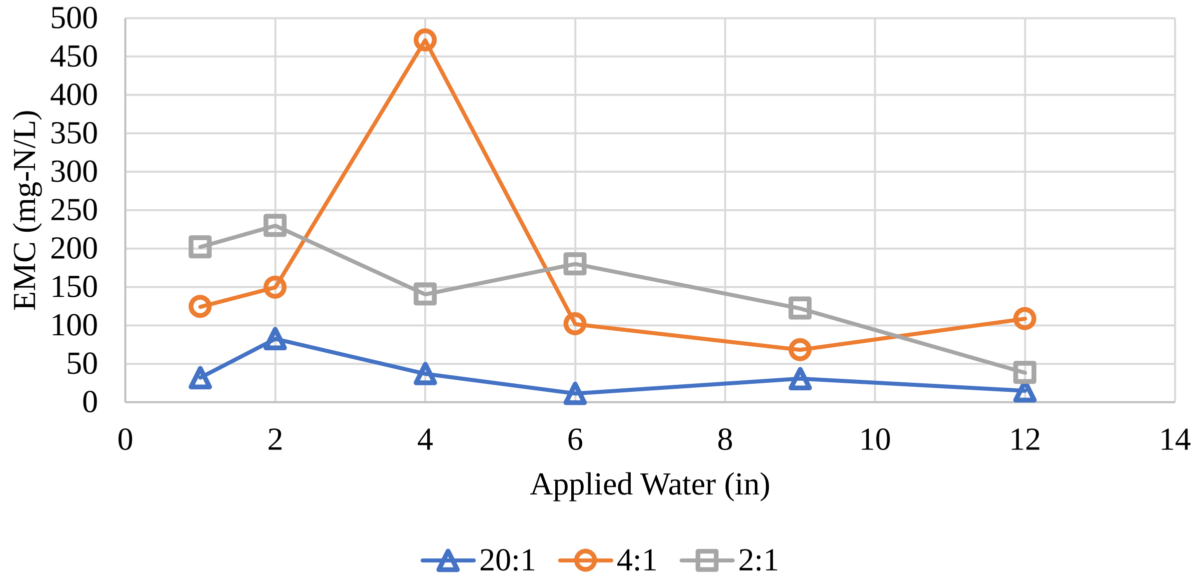
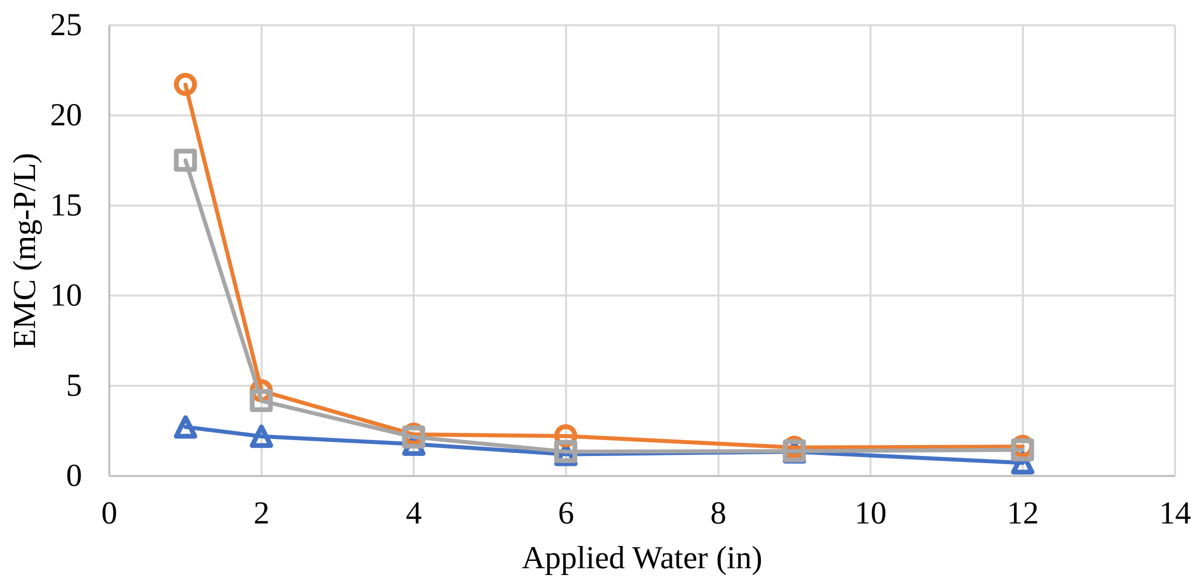


Figure 7-9: Greenwaste EMC values. Places where there are no points indicate the sample was too small to measure that value or there was no sample. 2:1 and 4:1 EMC values are not consistently higher or lower than each other, but typically show reduction in concentration.



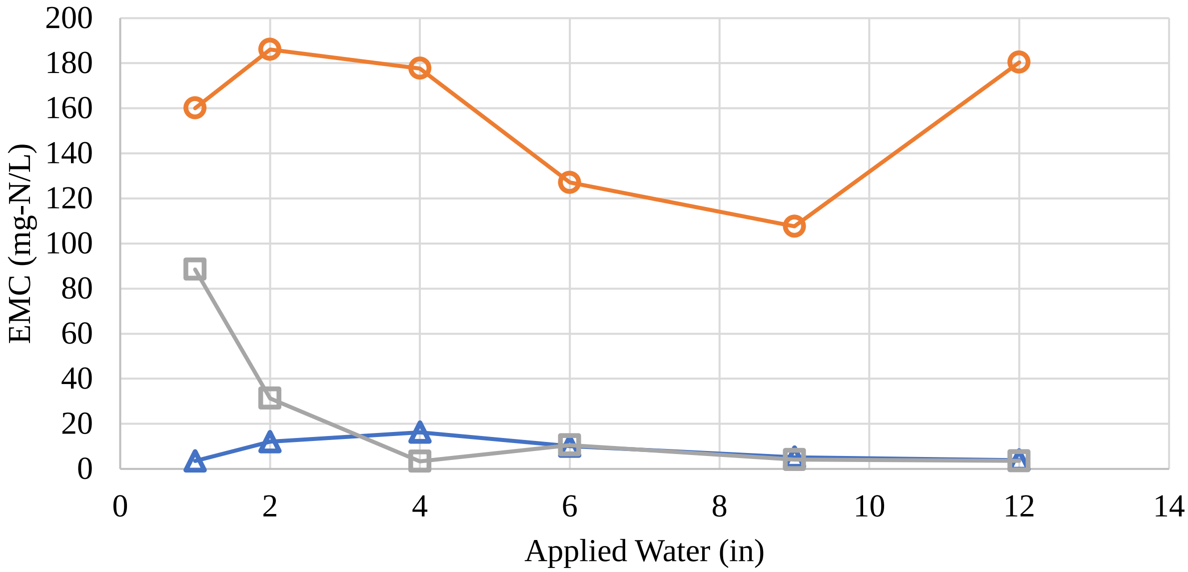
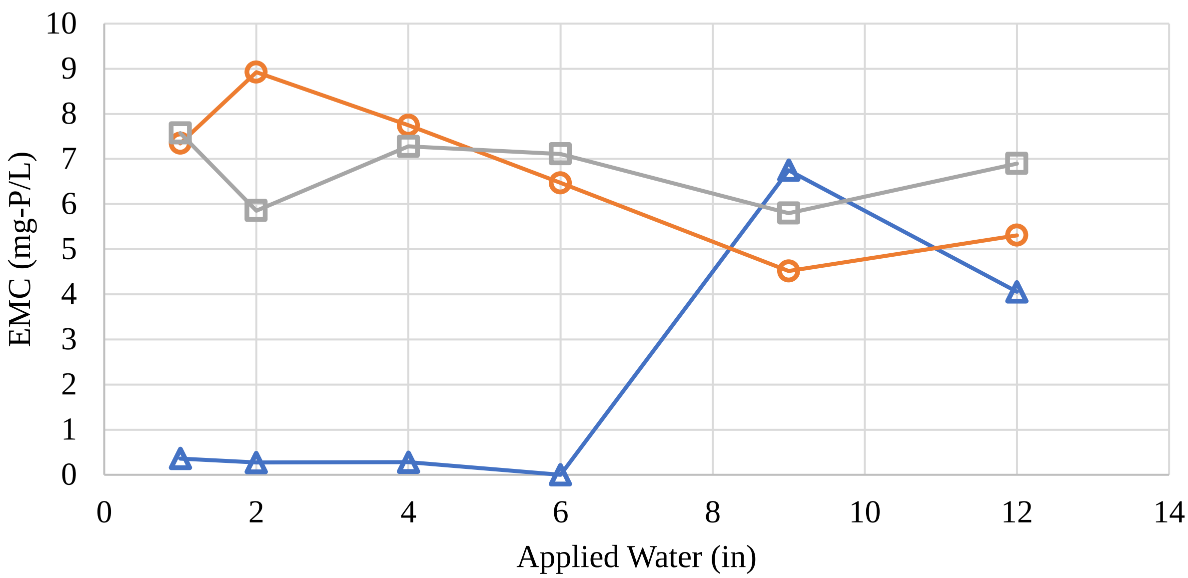


Figure 7-10: Topsoil EMC values. Places where there are no points indicate the sample was too small to measure that value or there was no sample. The higher sediment transport occurred for the 2:1 slope.



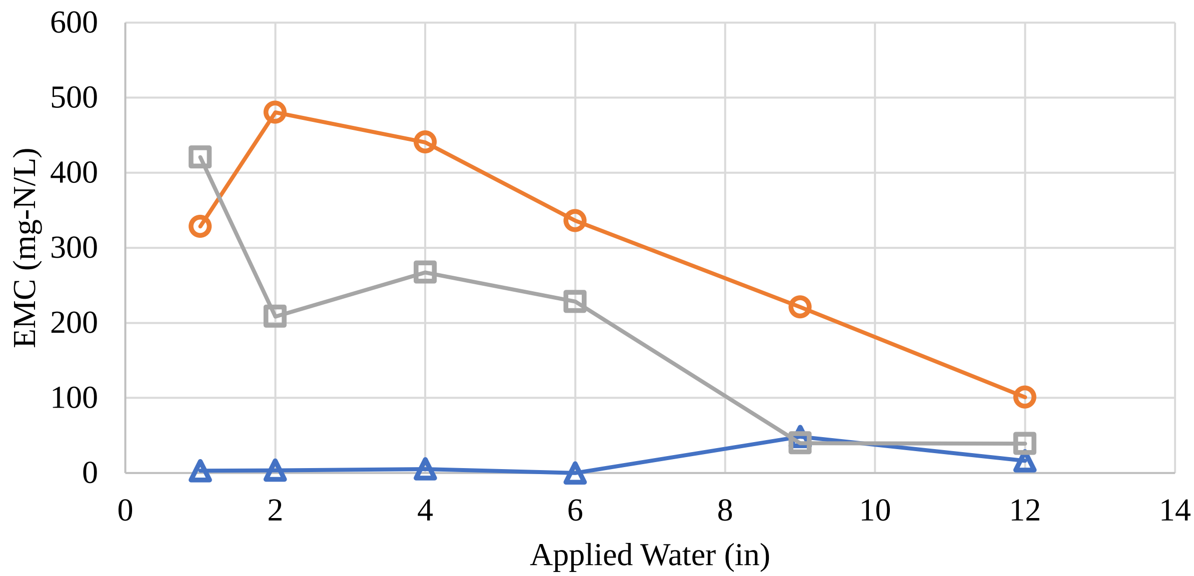
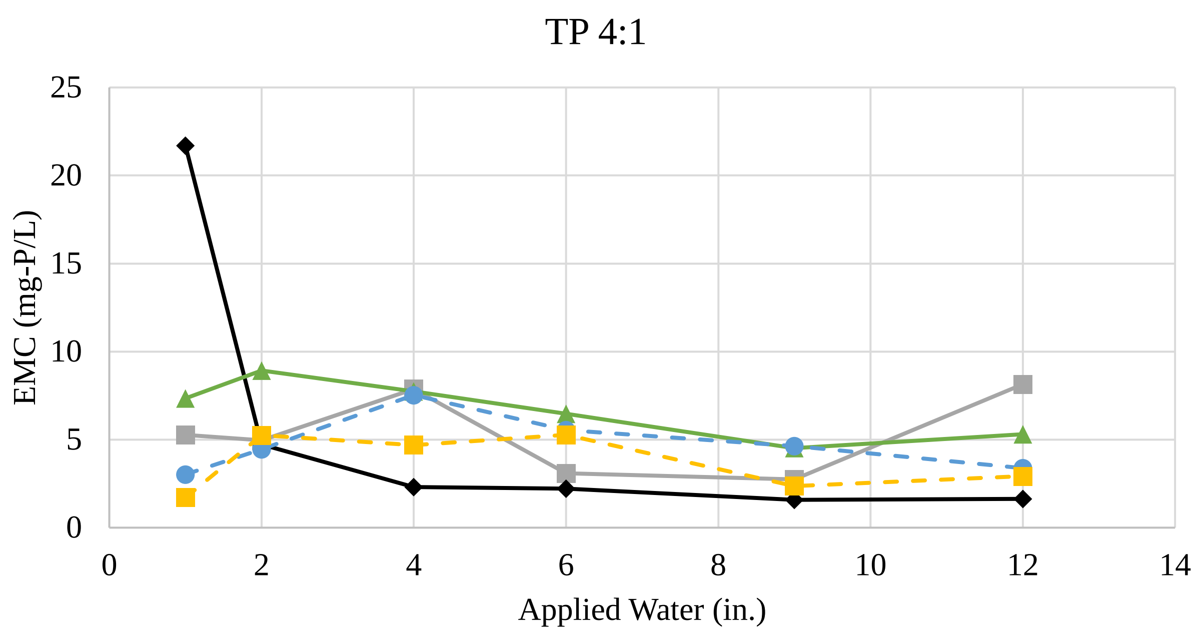


Figure 7-11: Biosolids EMC values. Places where there are no points indicate the sample was too small to measure that value or there was no sample. Sediment capture for this slope was very difficult due to the small volume produced. Smaller individual samples were taken to produce concentration values. Only one instance stood out for sediment transport where a large amount of sediment moved suddenly and was captured in the 4:1 slope. This did not occur more than once.



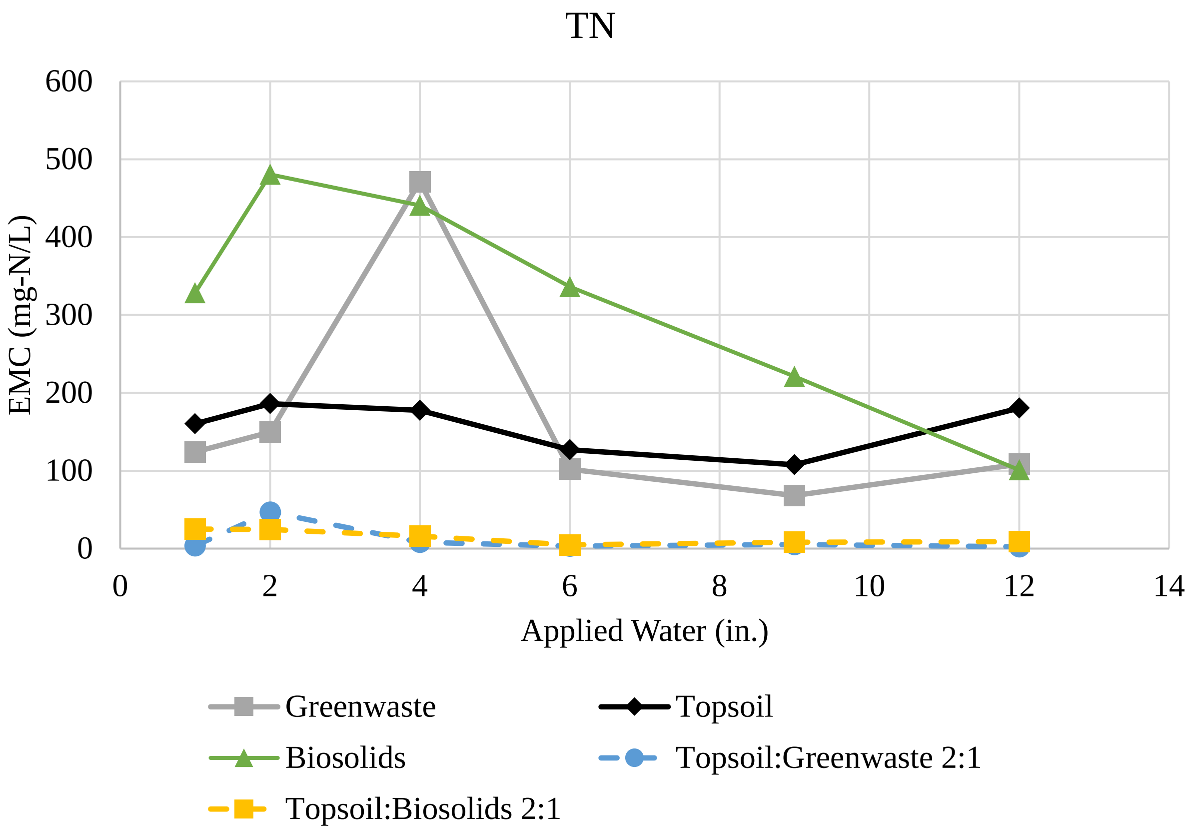
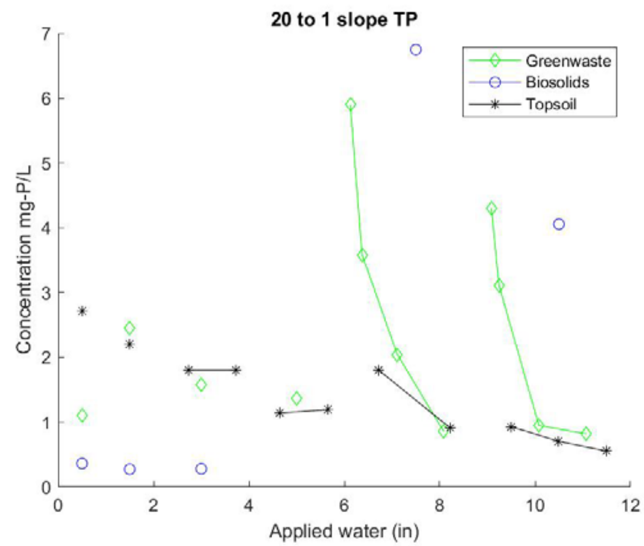
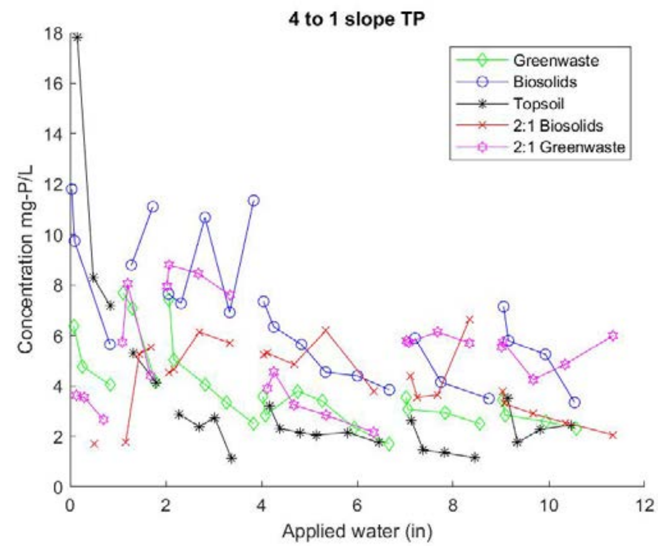


Figure 7-12: Total P and total N for the 4:1 slope trial with all five media types. Places where there are no points indicate the sample was too small to measure that value or there was no sample. TN values, except the one high greenwaste value, all show very clear reduction in the concentration of nitrogen with applied water. This is less evident in the phosphorus graph, but still occurs.


20 to 1 slope TP
Greenwaste
Biosolids
Topsoil
Concentration mg-P/L
Applied water (in)


4 to 1 slope TP
Greenwaste
Biosolids
Topsoil
2:1 Biosolids
2:1 Greenwaste
Concentration mg-P/L
Applied water (in)

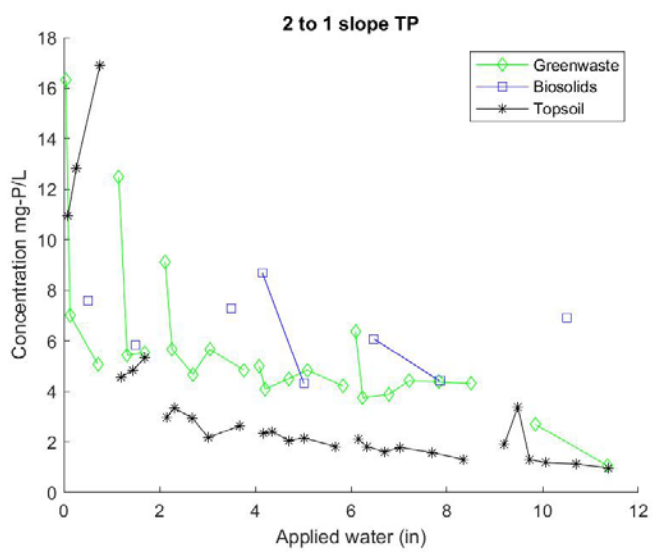
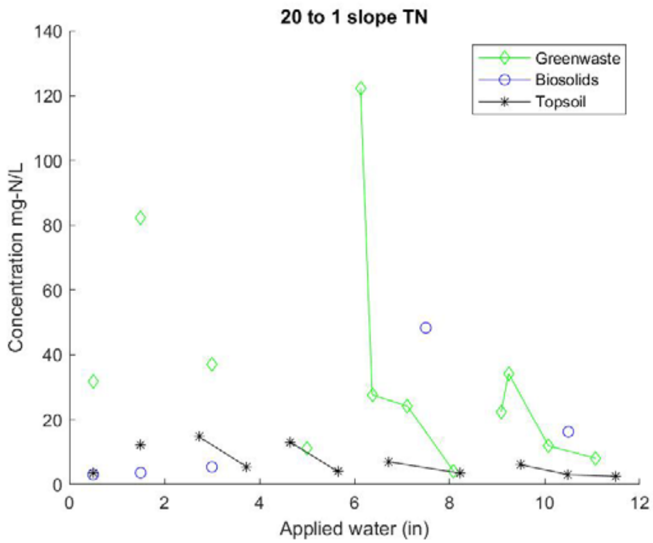
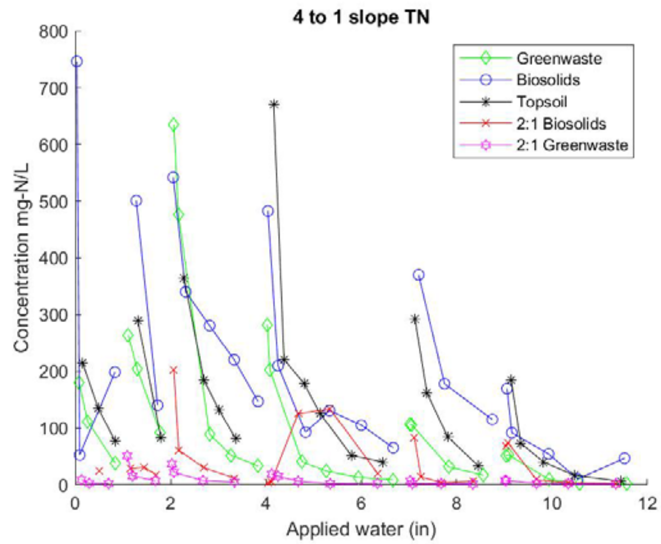

2 to 1 slope TP
Greenwaste
Biosolids
Topsoil
Concentration mg-P/L
Applied water (in)

Figure 7-13: Phosphorus concentrations at all slope angles. Each point represents a single grab sample taken for a short period of time during a full storm event. There are 6 storm events represented as connected points. There is a minimum of 1 point for small runoff volumes and a maximum of 6 points for larger volumes. Topsoil produced low concentrations of phosphorus, with larger volumes and biosolids had higher concentrations with lower volumes.


20 to 1 slope TN
Greenwaste
Biosolids
Topsoil
Concentration mg-N/L
Applied water (in)


4 to 1 slope TN
Greenwaste
Biosolids
Topsoil
2:1 Biosolids
2:1 Greenwaste
Concentration mg-N/L
Applied water (in)

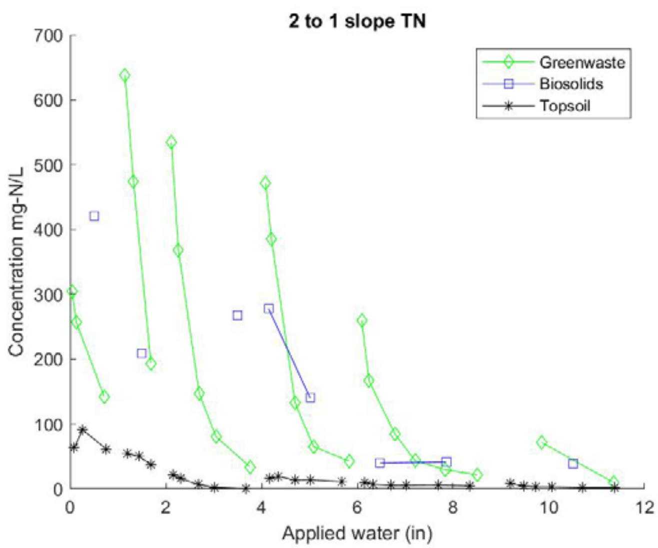

2 to 1 slope TN
Greenwaste
Biosolids
Topsoil
Concentration mg-N/L
Applied water (in)

Figure 7-14: Nitrogen concentrations at all slope angles. All points represent grab samples. The 2:1 mixtures had the lowest concentrations of TN, but also produced a large volume of water. At the 4:1 slope many of the grab samples from topsoil, biosolids, and greenwaste were similar, but the volume produced was much larger for the greenwaste which resulted in a larger EMC and mass transport.

APPENDIX F: NUTRIENT SPECIES COMPOSITION

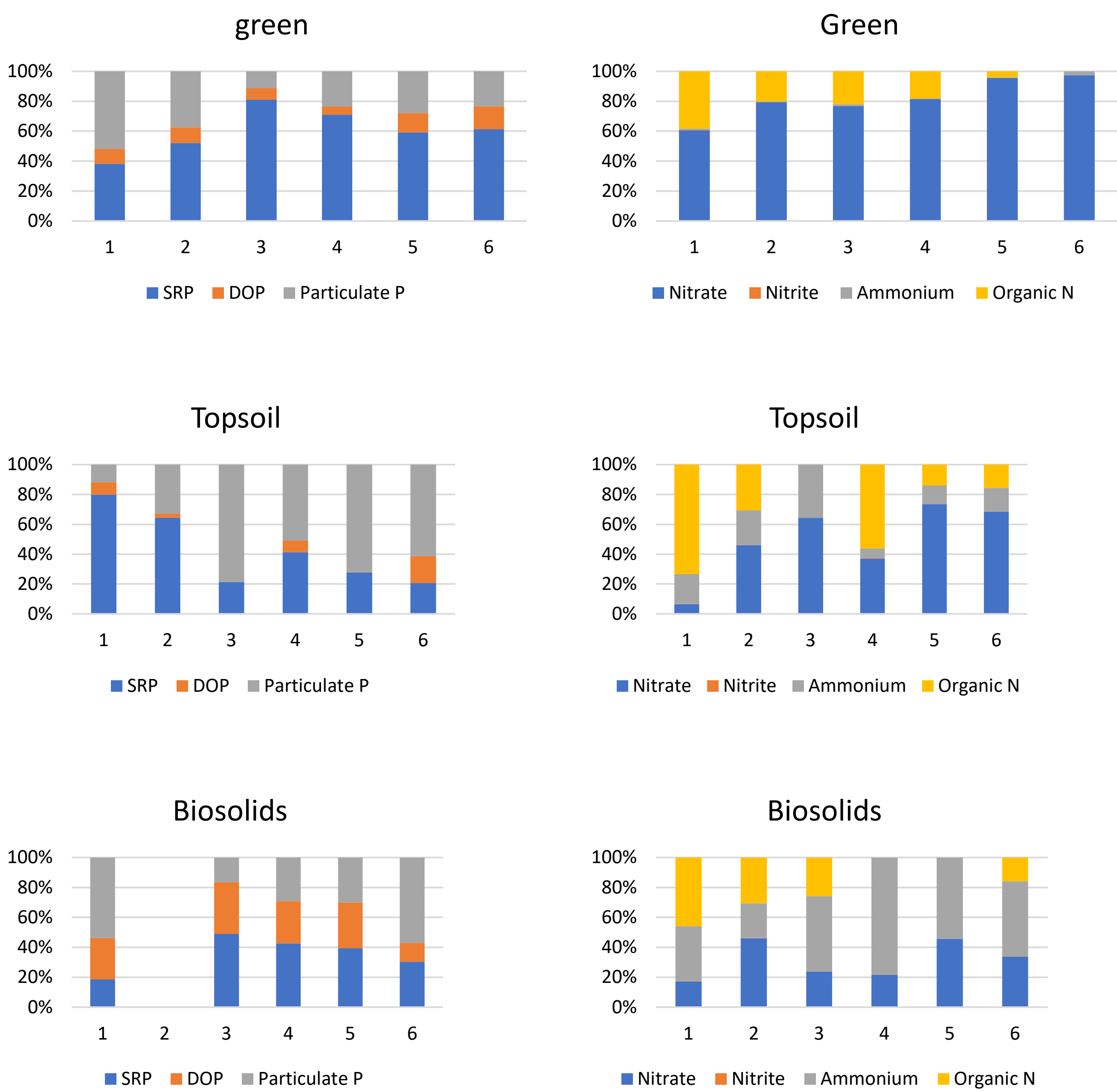


Figure 7-15: Percent breakdown of P and N species at the 2:1 slope.