Physical Properties of Varying Rain Garden Filter Bed Substrates Affect Saturated Hydraulic Conductivity©

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Both water flow through and retention time (Ksat) in filter bed substrates in combination with plants remediate polluted stormwater runoff in rain gardens. Two commonly used rain garden filter bed substrates were evaluated: sand (80% washed sand, 15% clay and silt fines and 5% pine bark v/v/v) and slate (100% expanded D-tank slate). Regression analyses showed that slate banded with increasing amounts of composted yard waste (CYW) resulted in a linear decrease in Ksat while, increasing amounts of pine bark (PB) banded resulted in a linear increase in Ksat. The amount of organic matter added to sand did not alter Ksat. Particle size distribution regression analyses showed that increasing the amount of CYW incorporated in sand caused coarse (>2.0 mm) size particles to increase linearly while, there was a quadratic effect on medium (0.5-2.0 mm) and fine (<0.5 mm) size particles. Amendment amount of CYW or PB with slate had no impact on particle size distributions in the coarse, medium, or fine particles.

INTRODUCTION

Stormwater control measures (SCMs) such as rain gardens (also referred to as bioretention cells) are designed to capture polluted stormwater runoff from impervious surfaces. Rain gardens are installed into the landscape by excavating the native soil, filling with an engineered filter bed substrate and planting, creating a depression to capture stormwater runoff and allow infiltration (Dietz, 2007). The environment created within the rain garden by the filter bed substrate and plants allows numerous remediation processes like adsorption, filtration, sedimentation, volatilization, ion exchange, plant uptake, and biological decomposition to occur (NCDENR, 2009).

Sand based filter bed substrates are recommended due to their suitable hydraulic conductivity (Ksat) (Davis et al., 2009; Hsieh and Davis, 2005). Pine bark (PB) is often used as an organic matter source in filter bed substrates to increase Ksat and denitrification; however, it does not provide much pollutant binding opportunities due to its low CEC. Drainage through the rain garden filter bed substrate needs to be slow in order to allow time for plant uptake and binding of the pollutants within the filter bed substrate. Little research has examined different sources and methods of adding organic matter to rain garden filter bed substrates. Rain garden filter bed substrates are combinations of soil and non-soil components and should be described by particle size distributions and Ksat (Kraus et al., 2014). Ksat values are preferred to be between 2.5-5.1 cm/h (NCDENR, 2009).

Sand filter bed substrates are heavy, expensive to ship, and may not be the best choice for stormwater remediation in rain gardens. Pledger (2012) found that slate as a rain garden filter bed substrate remediated all pollutants well in comparison to sand which remediated everything well except nitrogen (N). There are potential alternative filter bed substrates, organic matter sources, and methods of adding organic matter that can support plant growth and remediate polluted stormwater runoff similar to or better than the recommended sand filter bed substrates. The main objectives of this research were to: (1) Determine the role of different sources of organic matter and (2) Evaluate different combination methods and amounts of organic matter additions to filter bed substrates for their effect on particle size distribution and water and air filled fractions.

MATERIALS AND METHODS

An experiment was conducted as a randomized complete block design with a factorial treatment arrangement and three replications to address these objectives. Thirty-two substrates resulted from combinations of two filter bed substrates, two organic matter amendments, two combination methods, and four different organic matter amounts. The two filter bed substrates used were sand [80% washed sand, 15% clay and silt fines, and 5% pine bark (by vol)] (Wade Moore Equipment Company, Louisburg, North Carolina) and D-tank 100% expanded slate (Permatill, Carolina Stalite Company, Salisbury, North Carolina). Both sand and slate were amended with two different sources of organic matter: pine bark (PB) and composted yard waste (CYW) (City of Raleigh Yard Waste Recycling Center, Raleigh, North Carolina). Pine bark and CYW were added as either a band in the depths of 2.5, 5.1, 7.6 or 10.2 cm (1, 2, 3, or 4 in.) or by incorporation of 5, 10, 15, and 20% (v/v) (Fig. 1). Banding and incorporation applied approximately equivalent amounts of organic matter. Hydraulic conductivity was determined by packing each substrate into 1029 cm^3 (62.8 in^3) cylindrical polyvinyl chloride (PVC) columns (5.1 cm diameter, 50.8 cm height). For the banded treatments, 4 in. of either sand or slate were added to the bottom of the column, then the 2.5, 5.1, 7.6, or 10.2 cm (1, 2, 3, or 4 in.) band of CYW or PB was added before the column was topped off with either sand or slate. Columns were slowly saturated from the bottom and allowed to remain at saturation for 2 h. After this saturation period, water flow through the columns and out of an elbow fitting on the top of the column was caught for 5 min, measured, and used to calculate Ksat using Darcy's Law. Particle size distribution (three replications) was only determined for the incorporation combination method by placing oven dried samples of 350 g (12.4 oz) in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, Ohio) fitted with 13-sieve plates; 6.3 mm (0.25 in.), 4.0 mm (0.16 in.), 2.8 mm (0.11 in.), 2.0 mm (0.08 in.), 1.4 mm (0.06 in.), 1.0 mm (0.04 in.), 0.71 mm (0.03 in.), 0.5 mm (0.02 in.), 0.36 mm (0.01 in.), 0.25 mm (0.009 in.), 0.18 mm (0.007 in.), and 0.106 mm (0.004 in.) for 5 min. The sample from each sieve was weighed, and particle size was expressed as a percentage of the total weight of the sample. Percentages of total sample were then grouped into fine (<0.5 mm), medium (0.5-2.0 mm), and coarse (>2.0 mm) fractions as described by Drzal et al. (1999) for statistical analyses. All variables were subjected to regression analysis and were considered significant at $P \leq 0.05$ (SAS, 2001).

RESULTS

Slate amended by incorporation with either source of organic matter had higher Ksat values than sand (Fig. 2). Additionally, slate had larger percentages of coarse size particles and smaller percentages of fine size particles when compare to sand. Regression analyses showed that slate banded with increasing amounts of composted yard waste (CYW), from 2 to 10 cm (1 to 4 in.), resulted in a linear decrease of Ksat, while increasing amount of pine bark (PB) banded with slate resulted in a linear increase (Fig. 2A). Slate incorporated with PB at varying amounts also had a quadratic trend for medium particle sizes where 10% (45%) and 15% (45%) had the lowest percentages (data not shown).

There were no clear trends in Ksat when increasing the amount of organic matter added to sand by either banding or incorporating (Fig. 2B). Particle size distribution regression analyses showed that coarse (>2.0 mm) size particles in sand incorporated with varying amounts of CYW increased linearly (data not shown). Also, increasing the incorporated amount of CYW in sand had a quadratic trend on medium (0.5-2.0 mm) and fine (<0.5 mm) particle sizes. Sand incorporated with CYW at 10% (50%) had a higher percentage of medium sized particles than 5% (44%), 15% (45%), or 20% (42%). Fine size particles had the lowest percentage at 10% (40%) for sand incorporated with CYW than 5% (44.9%), 15% (42.5%), or 20% (45.1%).

DISCUSSION

Due to the nesting effect of different particle sizes within the filter bed substrate, particle size distribution impacts saturated hydraulic conductivity (Ksat) of rain garden filter bed substrates. Generally, slate has a larger percentage of coarse particles and less fine particles than sand allowing faster (at times too fast) water movement through the substrate. This effect is shown by the differences in Ksat between slate and sand. However, when slate is amended with a band of either organic matter source (PB or CYW), the Ksat is slowed compared to incorporation. Banding slate with 4 in. of CYW slowed Ksat significantly and to acceptable rates. Overall, slate generally has higher Ksat values than sand regardless of the combination method. However, banding of CYW with slate makes it have a slower, more comparable Ksat to sand banded with either organic matter source at any amount. Generally, Ksat of sand was not impacted by the amount of organic matter added for either banding or incorporation. Kraus et al. (2014) found that when using sand with an initial particle size distribution of 83% fine, 17% medium and 0.25% coarse particles, it needed to be amended to achieve a final particle size distribution of 67% fine, 30% medium, and 2% coarse to achieve adequate Ksat. The sand particle sizes for this study were all higher than these recommendations for incorporation with both organic matter sources and each increasing amount.

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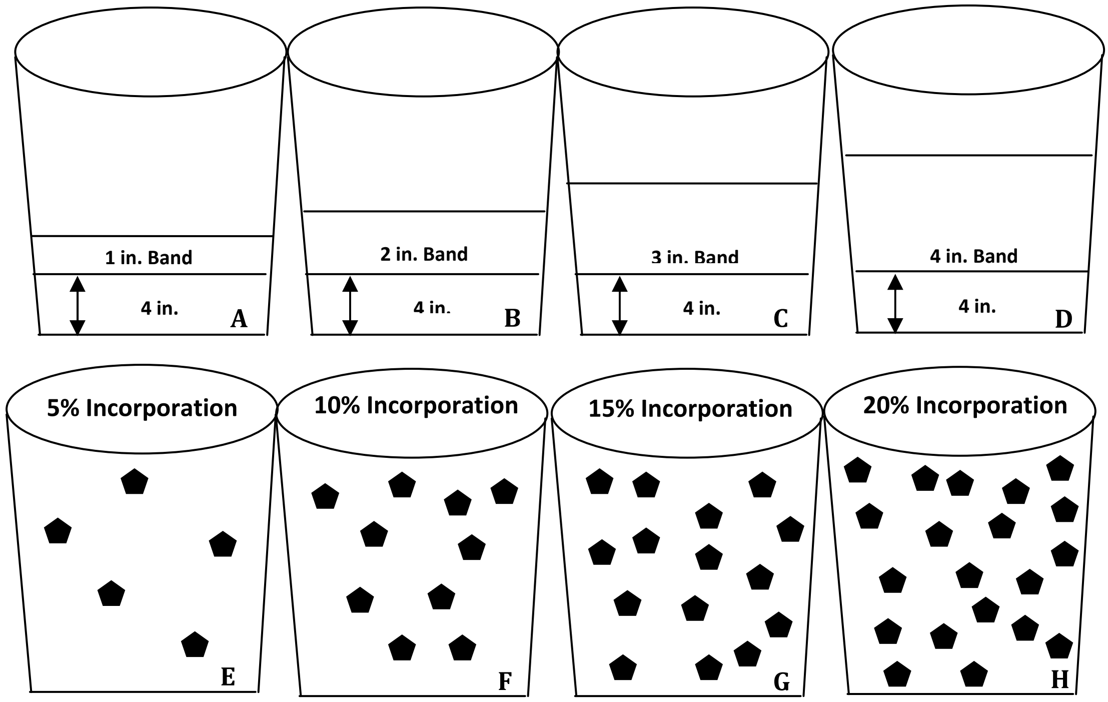

Fig. 1. Schematic of different filter bed substrate combination methods and organic matter amounts. The two organic matter amendments were added as either a band in the depths of 1, 2, 3, or 4 inches or by incorporation using approximately the same amounts of organic matter in the amounts of 5, 10, 15, and 20% (v/v). A: Combination method of banding with combination amount of 1 inch, B: Combination method of banding with combination amount of 2 inches, C: Combination method of banding with combination amount of 3 inches, D: Combination method of banding with combination amount of 4 inches, E: Combination method of incorporation with combination amount of 5%, F: Combination method of incorporation with combination amount of 10%, G: Combination method of incorporation with combination amount of 15%, and H: Combination method of incorporation with combination amount of 20%.

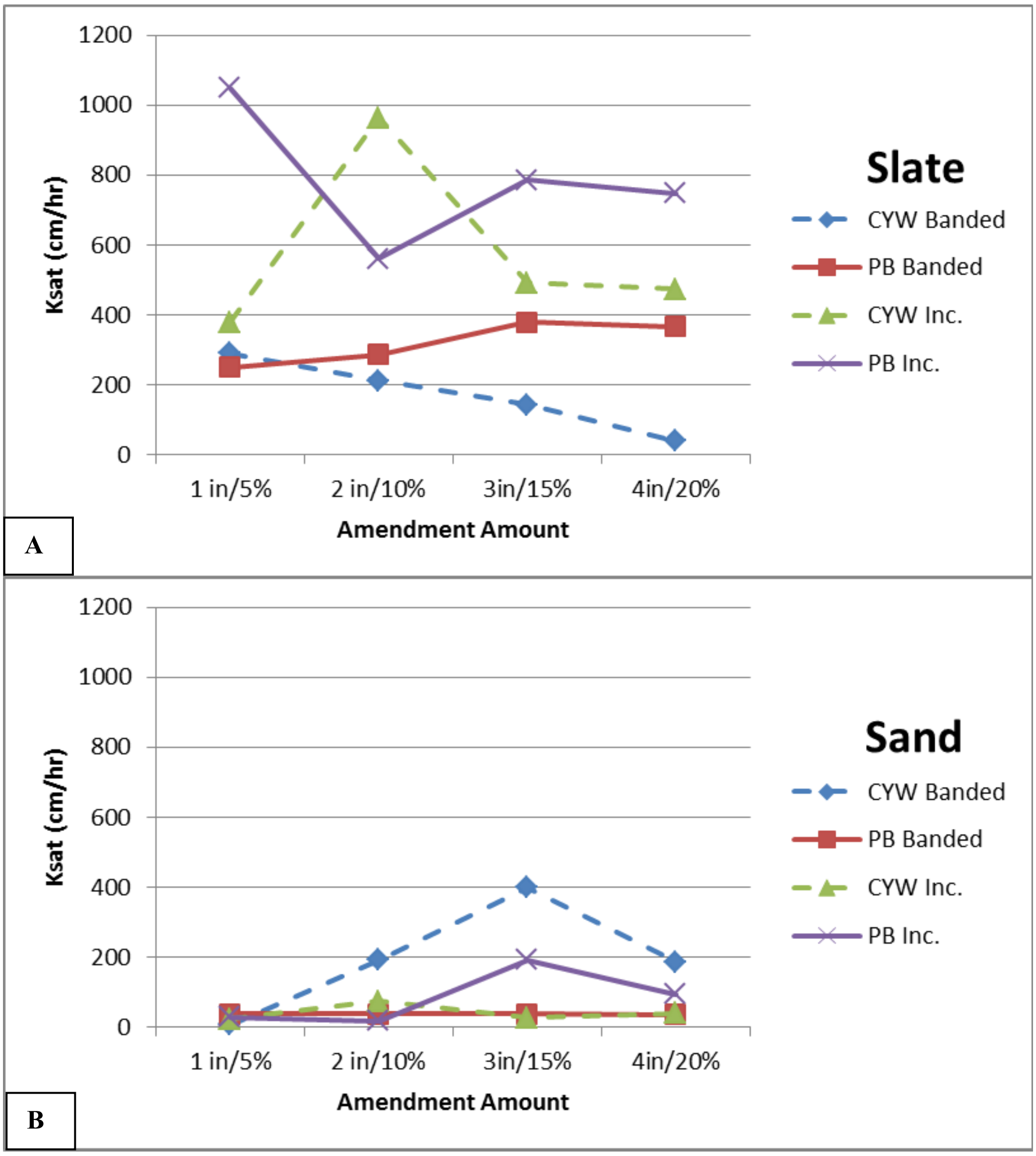

Fig. 2. Effect of amount of organic matter amendment on saturated hydraulic conductivity (Ksat) of a slate (A) and sand (B) rain garden filter bed substrate. The slate base was a 100% expanded D-tank slate. The sand rain garden filter bed substrate was a blend (v/v/v) of 80% washed sand, 15% clay and silt fines, and 5% pine bark. Organic matter amendments included pine bark (PB) and composted yard waste (CYW). Organic matter amendments were added as either a band in the depths of 1, 2, 3, or 4 inches or by incorporation using approximately the same amounts of organic matter in the amounts of 5, 10, 15, and 20% (v/v).