# Amending Soils for Enhanced Infiltration of Stormwater

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## Abstract

Rainfall events on urban compacted soils increase the volume and rate of stormwater runoff. A research study was conducted recently in North Carolina to investigate soil amendments to enhance infiltration into compacted soils. Sites were located in the coastal plain, piedmont, and mountain regions and the sites had sand, sandy clay, and sandy clay loam textured subsoils, respectively. The soil profiles were exhumed into the subsoils and compacted to simulate urban disturbed conditions. Physical treatments/amendments included compacted (control), shallow tillage (15 cm), and deep tillage (30 cm). Fertility amendments included agricultural lime and fertilizer according to soil test results. Triplicate plots were randomized on each of the sites. Fescue grass was seeded, mulched, and covered with jute matting. Steady state infiltration rate, bulk density, cone penetrometer, grass shoot biomass, and grass root biomass measurements were taken over the study period. Runoff from natural rainfall events was measured for twelve storm events at the two piedmont sites. Tillage greatly increased the infiltration rates and the effect remained after three years. There was evidence of some decline in infiltration rates at the mountain site, but none at the other sites, even though the bulk densities tended to increase over time at all sites. Doubling recommended lime rates, or adding compost, or water absorbing polyacrylamide usually had no effect on infiltration rates. The initial infiltration rates for compacted soils were usually < 1 cm hr$^{-1}$ but the rates improved over several years to up to 10 cm hr$^{-1}$. This was somewhat surprising, but the trend was evident at all sites. The tilled soils had infiltration rates of 20 to 35 cm hr$^{-1}$ at the end of at least two years. Because this far exceeds expected rainfall of 3 to 6 cm hr$^{-1}$ for 2 to 10 year recurrence storms, the results suggest that treated areas may be able to accept significant amounts of runoff from impervious areas.

## Introduction

Soil compaction during construction of our cities totally changes the hydrologic balance. The change is immediate and long lasting. The disturbance of soils by cutting, filling, and grading of the landscape creates soils that essentially act like impervious surfaces. The land area of compacted soils in cities often exceeds the land area of impervious surfaces, therefore they act together to transport the combined stormwater runoff into urban streams and to transport high total suspended sediment loads into the streams. This combined effect of large volumes of runoff and large loads of total suspended sediment totally changes our urban streams.

This research program has evaluated the effectiveness of enhanced infiltration as a stormwater system and best management practice, and has determined how best to amend the various types of compacted soil across North Carolina. The research was financially supported by the North Carolina Clean Water Management Trust Fund, Department of Environmental and Natural Resources to investigate new innovative stormwater systems.

Undisturbed, well managed soils and landscapes provide the largest stormwater detention and water quality treatment system that exists. If enhanced infiltration is properly implemented, it will not only reduce the amount of runoff from urban compacted soils and landscapes, but will have the capacity to receive and naturally handle runoff from impervious surfaces. In addition, enhanced infiltration normally can be done on areas to be landscaped and therefore no additional land area is needed; the landscape doubles as a stormwater system.

## Literature

Soils have the ability to absorb a large amount of rainfall; however, urban soils frequently have low infiltration rates. Soils in urban areas may be compacted for strength or unintentionally compacted due to construction activities (Gregory et al., 2006). Compaction caused by construction equipment is a serious problem affecting soil physical properties, including bulk density, porosity, and vegetative growth (Randrup et al. 1997). The amount, intensity and type of wheel traffic on a site during the construction phase influences soil compaction (Balbuena et al., 2002; Jurajuria et al., 1996; Lowery et al., 1994). Compaction is not limited to the surface layer, as Voorhees et al. (1986) documented increased bulk density as deep as 60 cm due to wheel traffic.

Reduced root growth has been shown to be a major consequence of soil compaction (Gilman et al., 1987; Alberty et al., 1984). Shallow rooted plants are more susceptible to drought stress and do not provide deep channels, created by roots, for water to infiltrate (Bouma et al., 1978; Hino et al., 1987; Bartens et al., 2008). The studies by Taylor et al. (1969) determined that soil resistance values above 2.5 Mpa are root limiting due to low soil moisture, compaction, or both. Several studies have demonstrated the negative correlation between root elongation and soil strength, with substantially lower rooting depth on compacted soils (Bengough et al., 1991; Balbuena et al., 2002; Chen et al., 2010). The detrimental effects on urban stream function from development and the challenges related to restoring degraded streams have been well documented (Booth et al., 1997; Violin et al., 2011).

An infiltration survey by Yang et al. (2011) found low infiltration rates in urban areas, 63 mm $hr^{-1}$ to less than 1 mm $hr^{-1}$. Other studies have shown poor infiltration due to compaction (Siyal, 2002; Woltemade, 2010). The increase in infiltration from tillage was also documented in a study by Lipiec (2005) that demonstrated tillage increasing infiltration by 61%. Infiltration measurements on recently developed sites in the area were below detection by the Cornell Sprinkling Infiltrometer method, while they were 3-39 cm $hr^{-1}$ for established lawn, meadow, and forested sites (Brown, 2012). Amending soil with compost has been shown to positively influence both soil physical properties and plant growth. Bazzoffi et al. (1998) measured improved infiltration and significantly less runoff attributed to compost incorporation in a clay loam soil.

## Methodology

Research was conducted in each of the three regions in North Carolina: the Sandhills, Piedmont, and Mountain regions at the following research stations: Sandhills Research Station, near Jackson Springs, NC in the Coastal Plain region – sandy cut and compacted subsoil site, hereafter referred to as the Sandhills (**SH**) site; Lake Wheeler Road Field Laboratory, Raleigh, NC in the Piedmont region – clay loam cut and compacted subsoil sites 1 and 2, hereafter referred to as Piedmont 1 (**P1**) and Piedmont 2 (**P2**) sites (these sites are adjacent to each other and site 2 was established a year after site 1 in order to investigate additional amendments); and Mountain Horticultural Crops Research Station, near Mills River, NC in the Mountain region – sandy clay loam cut and compacted subsoil site, hereafter referred to as the Mountain (**MT**) site.

Three basic tillage treatments were conducted using random replicated plots. The tillage treatments were compacted subsoil (control), compacted subsoil with shallow tillage (15 cm), and compacted subsoil with deep tillage (30 cm). The shallow tillage treatment was omitted at **P2**. The plots were split to evaluate liming rates as recommended by soil test and also at two times the recommended liming rate for the deep tillage. An additional treatment of an incorporated compost amendment was used at all sites except **P1**. A polyacrylamide amendment was also included at **MT**.

Rainfall quantity and runoff quantity and quality were measured at **P1** and **P2** sites for three to four months after establishment. Infiltration rates, biomass production, rooting depth, soil compaction, and penetrometer resistance were measured at all sites. The changes in infiltration rates and biomass production were measured at various intervals over 24 to 30 months after installation. Infiltration rates were compared with and without mower traffic.

The topsoil and vegetation were removed from a 0.5-ha area at each site to expose the subsoil. The area was then graded to achieve a uniform surface and with a slope of 5% or less for drainage. To simulate compaction from equipment traffic on construction sites, the graded area was further compacted by repeated passes with a smooth drum vibratory roller rented locally (10.9 Mg at **P1** and **P2**, 7.3 Mg at **SH**, 9.1 Mg at **MT** site). Eighteen, 28, 48, and 62 plots were established at **P1**, **P2**, **SH** and **MT** sites, respectively, to accommodate the full suite of treatments. Except at **SH**, the soil was first loosened to the required depth using a backhoe followed by rotary tillage to the desired depth. The compaction at these three sites prevented the tractor-mounted tillage equipment from penetrating the soil without first loosening it.

Particle size analysis was performed using the hydrometer method. **Table 1** presents the sand, silt, and clay contents of the exposed subsoils at the **SH**, **P1**, **P2**, and **MT** sites.

| | Particle Size Fraction (%) | | |
|---|---|---|---|
| | Sites | | |
| | SH | P1 & P2 | MT |
| Sand | 92 | 48 | 48 |
| Silt | 6 | 12 | 22 |
| Clay | 2 | 40 | 30 |
| Texture | Sand | Sandy Clay | Sandy Clay Loam |

**Table 1** - Particle size distribution for soils at each site.

Bulk soil samples from each plot were sent to the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Soil Testing Laboratory for analysis to determine the recommended fertilizer and lime amendments for fescue turf. **Table 2** presents the nutrient recommendations for each of the study sites.

| Nutrient Requirement | Sites | | |
|---|---|---|---|
| kg ha$^{-1}$ | SH | P1 & P2 | MT |
| N | 73 | 49 | 49 |
| P | 0 | 99 | 0 |
| K | 73 | 99 | 0 |
| Lime Requirement kg ha$^{-1}$ | 1,561 | 1,220 | 0 |
| Soil pH | 6.0 | 5.8 | 6.0 |

**Table 2** - Soil nutrient recommendations for fescue turf at each site.

## Runoff Volume Results

**P1 Site** – Based upon 12 storm events, an analysis was conducted to determine the amount of runoff that would be expected for various storms on sites in the Piedmont region. In general, statistical trends between relative runoff and storm total rainfall were weak, likely due to variability in storm duration and intensity as well as soil moisture conditions **(Figure 1)**. Compacted plots often had runoff exceeding 50% of rainfall amount (nine of 12 events), whereas shallow tilled plots runoff exceeded 35% of rainfall on only two occasions and deep tilled plots runoff never exceeded 10% of rainfall amounts for any storm.

Because there were no clear relationships between rainfall characteristics and runoff, the average runoff as a percent of rainfall is a useful way to evaluate the data. The percent runoff from rainfall at the **P1** site averaged 41.3% for compacted, 10.9% for shallow tillage, and 2.6% for deep tillage for the twelve storm events with rainfall events ranging up to 6.07 centimeters. In most cases there were not significant differences between shallow tilled and deep tilled treatments, except for the two storms with the highest total rainfall. This generally supports the idea that deeper tillage can provide greater capacity to absorb rainfall and reduce runoff, but that gains may only occur for large storms.

**P2 Site** – The runoff pattern was similar to what occurred at the **P1** site when the **P2** site was established and tested the following year. The percent runoff from rainfall at the **P2** site averaged 32.2% for compacted, 4.2% for deep tillage, and 4.9% for deep tillage + compost for the twelve storm events with rainfall events ranging up to 3.43 centimeters **(Figure 2)**. The addition of compost did not significantly affect the amount of runoff at this site.

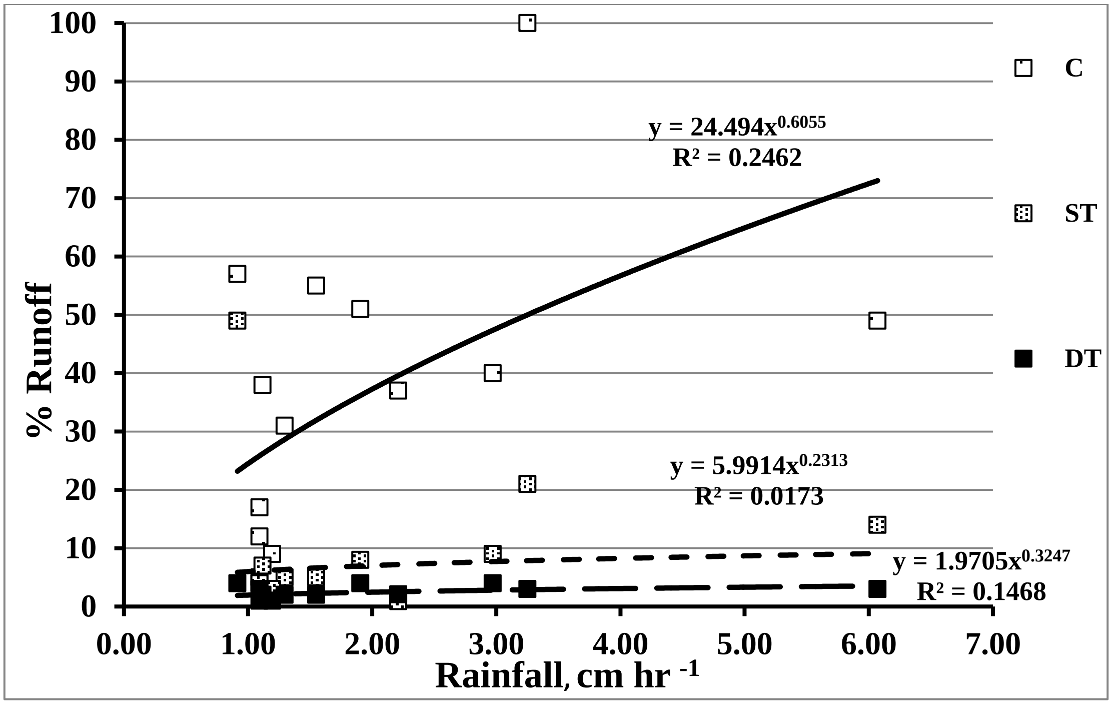

**Figure 1** - Rainfall total compared to runoff at the **P1** during the first 4 months of establishment for the compacted (**C**), shallow tilled (**ST**), and deep tilled (**DT**) plots. Trends are shown for reference, but statistical relationships were weak.

## Infiltration Results

Infiltration measurements were made of the plots at each of the sites using the Cornell Sprinkling Infiltrometer. The shallow tillage and deep tillage treatments **(Figure 3)** significantly increased the infiltration rate in all textures of soils at the four sites. No significant increase in infiltration rate was found with compost treatments.

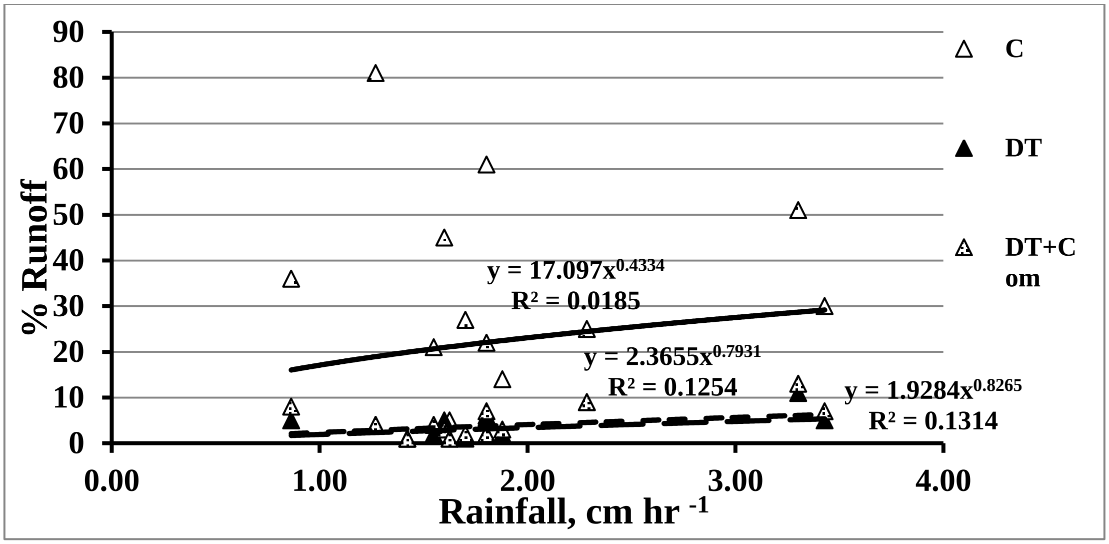

**Figure 2** - Rainfall total compared to runoff at the **P2** during the first 4 months of establishment for the compacted (**C**), deep tilled (**DT**), and deep tilled + compost (**DT + Com**) plots. Trends are shown for reference, but statistical relationships were weak.

**SH Site** – Infiltration measurements were taken 1, 5, 17, 24 and 28 months after establishing plots at the **SH** site. The mean infiltration rate was 6.7 cm hr$^{-1}$ for compacted plots, 33.4 cm hr$^{-1}$ for the shallow tillage, and 34.6 cm hr$^{-1}$ for the deep tillage plots. Therefore, deep tillage increased the mean infiltration rates by 515%. Due to increased infiltration rates of compacted plots and reduced infiltration rates of deep tillage plots, at the end of the period the infiltration rates for deep tillage was reduced to 305% more than the compacted plots.

**P1 Site** – Infiltration measurements were taken 4, 15, 21, 27 and 31 months after establishing plots at the **P1** site. The mean infiltration rate was 4.45 cm hr$^{-1}$ for compacted plots, 22.82 cm hr$^{-1}$ for the shallow tillage, and 26.50 cm hr$^{-1}$ for the deep tillage plots. Therefore, deep tillage increased the mean infiltration rates by 596%. Due to increased infiltration rates of compacted plots and reduced infiltration rates of deep tillage plots, at the end of the period the infiltration rates for deep tillage was reduced to 404% more than the compacted plots.

**P2 Site** – Infiltration measurements were taken 6, 13 and 18 months after establishing plots at the **P2** site. The mean infiltration rate was 6.1 cm hr$^{-1}$ for compacted plots and 23.6 cm hr$^{-1}$ for the deep tillage plots. Therefore, deep tillage increased the mean infiltration rates by 385%. Due to increased infiltration rates of compacted plots and reduced infiltration rates of deep tillage plots, at the end of the period the infiltration rates for deep tillage was reduced to 244% more than the compacted plots.

**MT Site** – Infiltration measurements were taken 2, 3, 21 and 27 months after establishing plots at the **MT** site. The mean infiltration rate was 6.1 cm hr$^{-1}$ for compacted plots, 31.0 cm hr$^{-1}$ for the shallow tillage, and 32.9 cm hr$^{-1}$ for the deep tillage plots. Therefore, deep tillage increased the mean infiltration rates by 540%.

Due to increased infiltration rates of compacted plots and reduced infiltration rates of deep tillage plots, at the end of the period the infiltration rates for deep tillage was reduced to 281% more than the compacted plots.

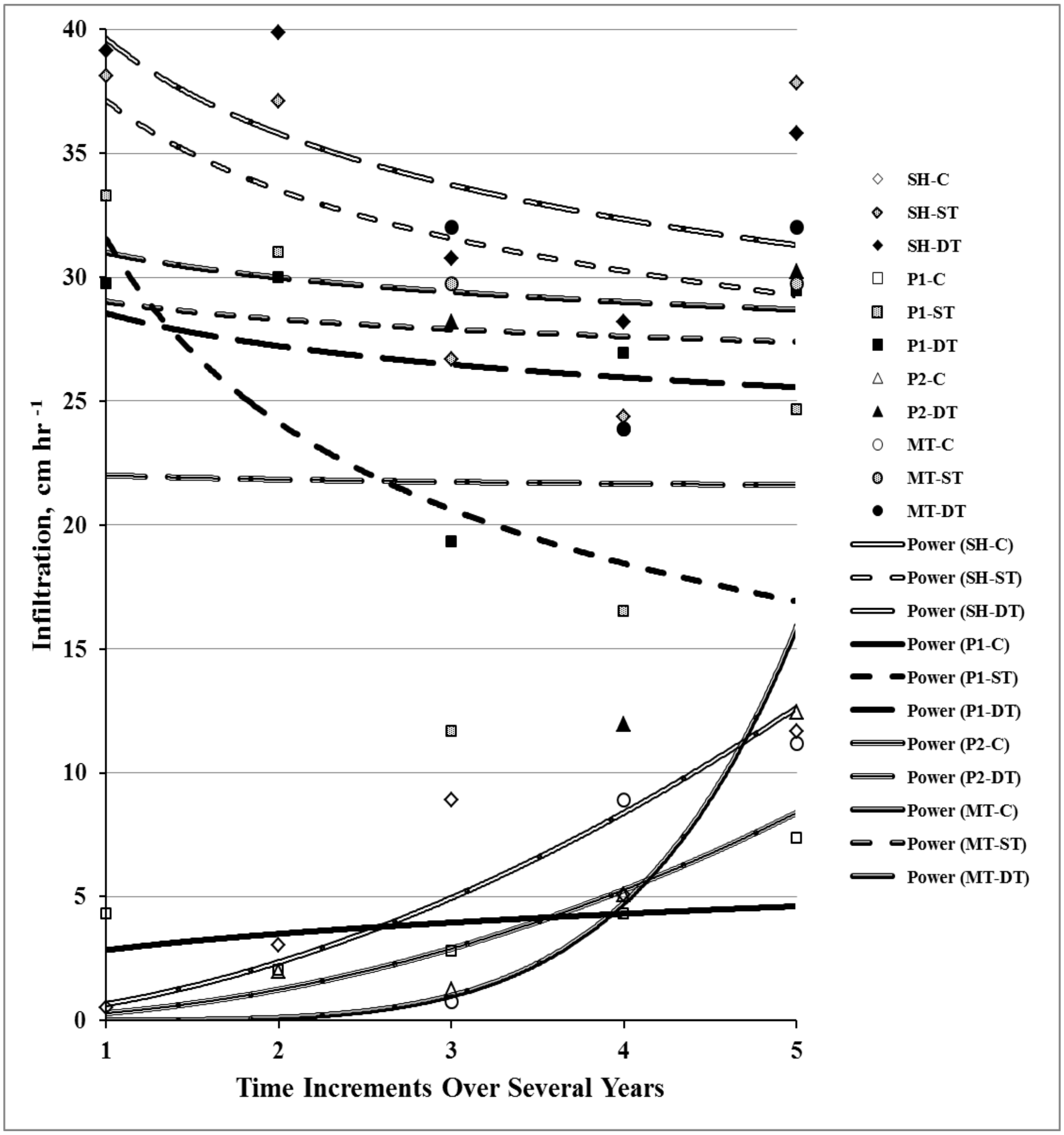

**Figure 3** - Infiltration rates compared to relative times up to 2 to 2.5 years after plot establishment for each of the sites and treatments.

## Water Quality Results

**P1 Site** – Water quality samples were collected for each of the twelve rainfall runoff events at the **P1** site during the growing season. The samples were analyzed for total suspended solids (TSS) and turbidity (NTU). The cumulative total sediment loss for the twelve storm events is shown in **Figure 4**, demonstrating the reduction in erosion losses with the tillage treatment were somewhat in proportion to the reduction in runoff. Turbidity was also measured in the runoff samples and there was no clear difference among the treatments. This illustrates the difference between measurements of sediment in the runoff versus turbidity, which can be high even with low levels of erosion due to the nature (particle size distribution) of the displaced soil. The effects of erosion on the disturbed areas being stabilized, as well as impacts on receiving waters, are better determined by measuring the sediment losses than turbidity.

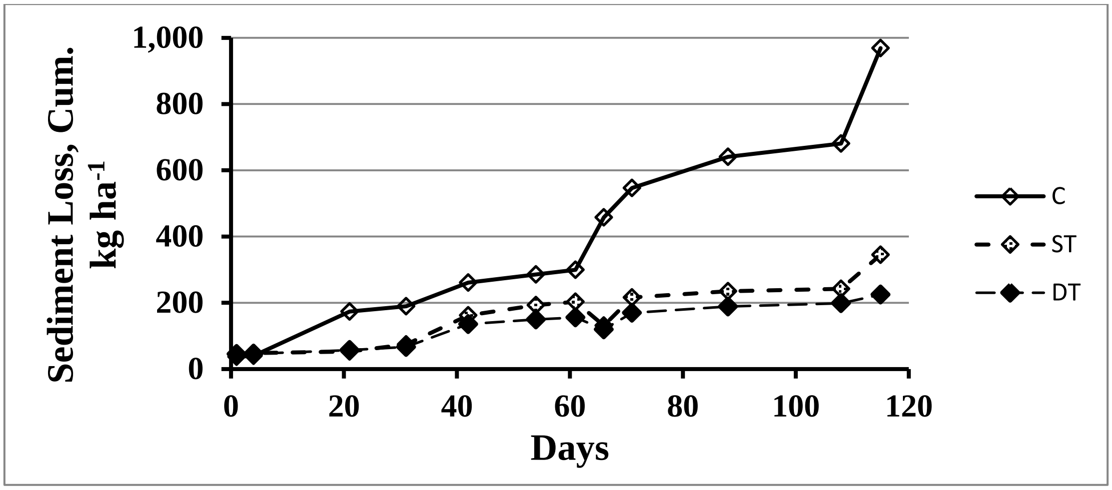

**Figure 4** - Cumulative sediment loss at **P1** for the compacted (**C**), shallow tilled (**ST**), and deep tilled (**DT**) plots**.**

**P2 Site** – Similar to **P1**, **P2** had much higher sediment losses from the compacted plots than from the tilled **(Figure 5)**. The incorporation of 5 cm of compost did not have any impact on erosion from the plots, similar to the runoff volume results. Turbidity was also not clearly related to treatment, which was again similar to **P1**.

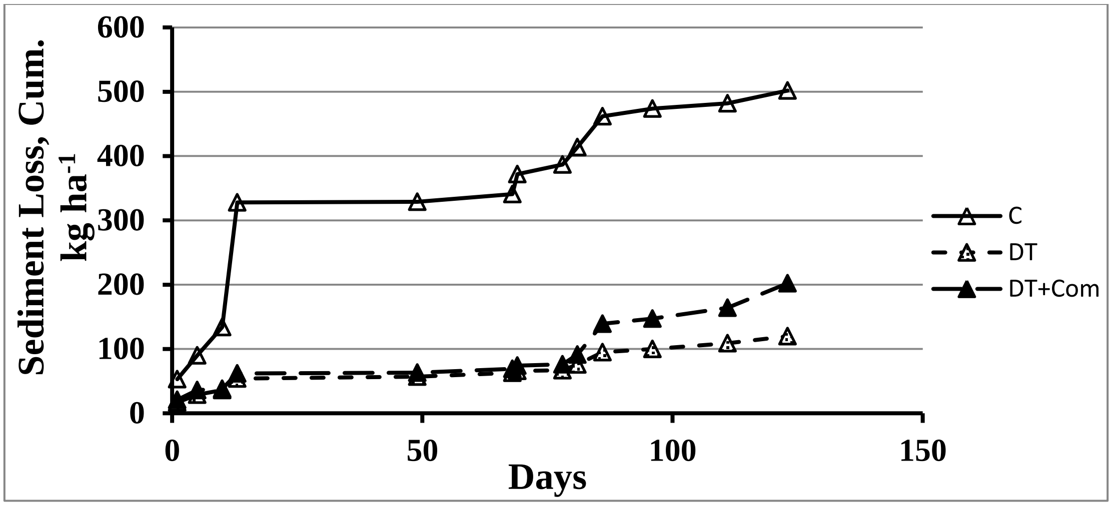

**Figure 5** - Cumulative sediment loss at **P2** for compacted (**C**), deep tilled (**DT**), and deep tilled + compost (**DT + Com**) treatments

## Cone Penetrometer Results

Cone penetrometer measurements were used to evaluate the depth and degree of compaction (i.e., root resistance) in the plots. **Figures 6** illustrates the mean results of the cone penetrometer analysis for **P1** site. The dotted vertical line at 2.5 Mpa shows the density above which root growth is typically considered inhibited. Results indicate significant improvement in root growth conditions for the shallow and deep tilled plots.

The deep tilled plots had the lowest resistance and for the greatest depth at all four sites. The shallow tilled plots exceeded the 2.5 Mpa density at about mean depth of 27 cm, corresponding to depths below that of the tillage amendment. The compacted plots exceeded the 2.5 Mpa resistance at about mean depth of 3 cm.

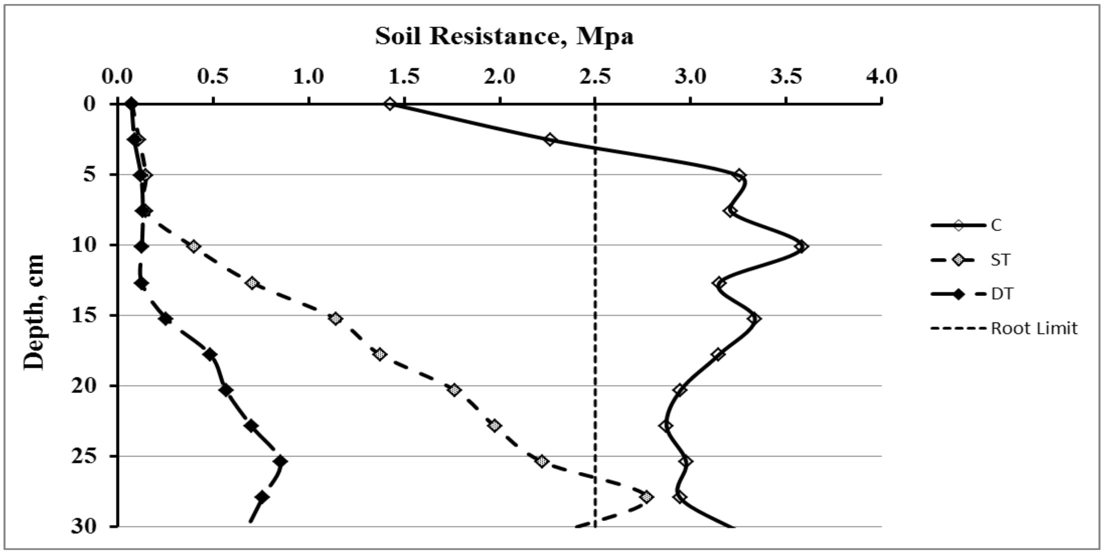

**Figure 6** - Soil resistance at **P1** for compacted (**D**), shallow tilled (**ST**), and deep tilled (**DT**) plots with depth below the ground surface.

## Plant Growth

The compacted plots had 25 to 33% less grass coverage than the deep tilled and shallow tilled plots, respectively. The grass shoot weight was not significantly different for the shallow tilled, deep tilled, and compacted plots with or without compost at the **SH** site and the **MT** site. However, the grass shoots weight was 169% greater for the shallow tilled plots and 166% greater for the deep tilled plots than for the compacted plots at **P1**. The root weight was 200% greater for the shallow tilled plots as compared with the compacted plots at **P1**, and the root weight was 333% greater for the deep tilled plots as compared with the compacted plots at **P1**.

## Conclusions

Research will be needed to model longer time periods and different conditions in order to build runoff coefficients and curve numbers with reasonable confidence. Various types of tillage equipment, methods of tillage, amendments and rates, and alternative species will need to be fully explored. However this research study has demonstrated that the tillage and vegetated systems tested were highly successful in improving infiltration in a wide variety of soils and that amended urban soils can provide a viable stormwater detention system.

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