IMPACT OF SOIL COMPACTION ON INFILTRATION FOR RAIN GARDENS

Annotated Bibliography

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Author(s): Burton, G.A. and R.E. Pitt
Year: 2002
Title: "Case study to measure infiltration rates in disturbed urban soils"
Book: *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*, 389-397
Study Type: Field
Abstract: A case study that was conducted by Pitt et al. (1999) that investigated infiltration rates in disturbed urban soils. These types of data can be used to more accurately predict watershed hydrology and associated receiving water problems, compared to using published information for natural soil conditions. The results presented in the following example show how site measurements can be significantly different from published and traditional data. This case study is presented as an example of how this type of study can be conducted to obtain this critical, site-specific information.
Key Point(s): A series of double-ring infiltrometer tests were conducted in disturbed urban soils in Alabama to determine the effects of soil moisture, soil texture, and compactness on infiltration rates. Compaction was tested using a DICKEY-john cone penetrometer and compaction was determined to be when measurements were above 300 psi. They found that large errors in infiltration rates can occur when using soil maps or models, because they ignore compaction. Soil compaction can be used to more accurately predict stormwater runoff quantity when compared to models and soil maps.

Author(s): Gregory, J.H, M.D. Dukes, P.H. Jones and G.L. Miller
Year: 2006
Title: "Effect of urban soil compaction on infiltration rate"
Journal (Issue): *Journal of Soil and Water Conservation*, 61(3), 117-124
Study Type: Field
Abstract: Inadvertent soil compaction at the urban lot scale is a process that reduces infiltration rates, which can lead to increased stormwater runoff. This is particularly important in low impact development strategies where stormwater is intended to infiltrate rather than flow through a traditional stormwater network to a detention basin. The effect of compaction on infiltration rates on sandy soils in North Central Florida was measured with a double ring infiltrometer on urban construction sites and across various levels of compaction. Average non-compacted infiltration rates ranged from 377 to 634 mm hr^{-1} (14.8 to 25.0 in hr^{-1}) for natural forest, from 637 to 652 mm hr^{-1} (25.1 to 25.7 in hr^{-1}) for planted forest, and 225 mm hr^{-1} (8.9 in hr^{-1}) for pasture sites. Average infiltration rates on compacted soils ranged 8-175 mm hr^{-1} (0.3-6.9 in hr^{-1}), 160 to 188 mm hr^{-1} (6.3 to 7.4 in hr^{-1}), and 23 mm hr^{-1} (0.9 in hr^{-1}) for the same respective sites. Although there was wide variability in infiltration rates across both compacted and non-compacted sites, construction activity or compaction treatments reduced infiltration rates 70 to 99 percent. Maximum compaction as measured with a cone penetrometer occurred in the 20 to 30 cm (7.9 to 11.8 in) depth range. When studying the effect of different levels of compaction due to light and

heavy construction equipment, it was not as important how heavy the equipment was but whether compaction occurred at all. Infiltration rates on compacted soils were generally much lower than the design storm infiltration rate of 254 mm hr^{-1} (10.0 in hr^{-1}) for the 100-yr, 24-hr storm used in the region. This implies that construction activity in this region increases the potential for runoff and the need for large stormwater conveyance networks not only due to the increase in impervious area associated with development but also because the compacted pervious area effectively approaches the infiltration behavior of an impervious surface.
Key Point(s): "Measuring infiltration rates is a lengthy procedure compared to measuring cone index. Therefore, cone index could be used to quickly and efficiently identify areas of a development that have been exposed to compaction and are thus contributing to decreased infiltration rates." Rapid assessment of soil compaction through the use of a cone penetrometer can provide valuable information on impacts to infiltration rates, but may only be applicable to types of soils similar to those in the study area (North Central Florida).

Author(s): Hamza, M.A. and W.K. Anderson
Year: 2005
Title: "Soil compaction in cropping systems: A review of the nature, causes and possible solutions"
Journal (Issue): *Soil & Tillage Research*, 82(2005):121-145
Study Type: Literature Review
Abstract: Soil compaction is one of the major problems facing modern agriculture. Overuse of machinery, intensive cropping, short crop rotations, intensive grazing and inappropriate soil management leads to compaction. Soil compaction occurs in a wide range of soils and climates. It is exacerbated by low soil organic matter content and use of tillage or grazing at high soil moisture content. Soil compaction increases soil strength and decreases soil physical fertility through decreasing storage and supply of water and nutrients, which leads to additional fertilizer requirement and increasing production cost. A detrimental sequence then occurs of reduced plant growth leading to lower inputs of fresh organic matter to the soil, reduced nutrient recycling and mineralization, reduced activities of micro-organisms, and increased wear and tear on cultivation machinery. This paper reviews the work related to soil compaction, concentrating on research that has been published in the last 15 years. We discuss the nature and causes of soil compaction and the possible solutions suggested in the literature. Several approaches have been suggested to address the soil compaction problem, which should be applied according to the soil, environment and farming system.
The following practical techniques have emerged on how to avoid, delay or prevent soil compaction: (a) reducing pressure on soil either by decreasing axle load and/or increasing the contact area of wheels with the soil; (b) working soil and allowing grazing at optimal soil moisture; (c) reducing the number of passes by farm machinery and the intensity and frequency of grazing; (d) confining traffic to certain areas of the field (controlled traffic); (e) increasing soil organic matter through retention of crop and pasture residues; (f) removing soil compaction by deep ripping in the presence of an aggregating agent; (g) crop rotations that include plants with deep, strong taproots; (h) maintenance of an appropriate base saturation ratio and complete nutrition to meet crop requirements to help the soil/crop system to resist harmful external stresses.
Key Point(s): Even though the focus is on agricultural systems, this is a good introduction to soil compaction issues and how they could be addressed.

Author(s): Le Coustumer, S., T.D. Fletcher, A. Deletic, S. Barraud and J.F. Lewis
Year: 2009
Title: "Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation"
Journal (Issue): *Journal of Hydrology*, 376(2009):16-23
Study Type: Field and Laboratory
Abstract: In order to evaluate the long-term performance of stormwater biofilters, a study was undertaken to assess their hydraulic conductivity. Despite variability in conductivity (40% being below the recommended range of 50–200 mm/h, 43% within it, and 17% above), treatment performance is unlikely to be affected, as most systems are over-sized such that their detention storage volume compensates for reduced media conductivity. The study broadly reveals two types of systems: some with a high initial conductivity (>200 mm/h) and some with a low initial value (<20 mm/h). Significant reduction in conductivity is evident for biofilters in the former group, although most are shown to maintain an acceptably high conductivity. Those with initially low conductivity do not change greatly over time. Site characteristics such as filter area (relative to catchment area), age and inflow volume were not useful predictors of conductivity, with initial conductivity of the original media being the most powerful explanatory variable. It is clear therefore, that strict attention must be paid to the specification of original filter media, to ensure that it satisfies design requirements.
Key Point(s): Laboratory experiments have the inherent problem of disturbance and soil compaction in the laboratory cannot be fully evaluated. Field work on in situ soil compaction needs to be performed in order to determine its impact on infiltration and other hydraulic performance parameters.

Author(s): Pitt, R., S. Chen and S. Clark
Year: 2001
Title: "Infiltration through compacted urban soils and effects on biofiltration design"
Journal (Issue): *Low Impact Development Roundtable Conference, Baltimore MD, July 2001*
Study Type: Review of Previous Laboratory and Field Studies
Abstract: The effects of urbanization on soil structure can be extensive. Infiltration of rain water through soils can be greatly reduced, plus the benefits of infiltration and biofiltration devices can be jeopardized. This paper is a compilation of results from several recent and on-going research projects that have examined some of these problems, plus possible solutions. Basic infiltration measurements in disturbed urban soils were conducted during the EPA-sponsored project by Pitt, *et al* (1999b), along with examining hydraulic and water quality benefits of amending these soils with organic composts. Prior EPA-funded research examined the potential of groundwater contamination by infiltrating stormwater (Pitt, *et al*, 1994, 1996, and 1999a). In addition to the information obtained during these research projects, numerous student projects have also been conduced to examine other aspects of urban soils, especially more detailed tests examining soil density and infiltration during lab-scale tests, and methods and techniques to recover infiltration capacity of urban soils. This paper is a summary of this information and it is hoped that it will prove useful to both stormwater practice designers and to modelers.
Key Point(s): Same as Burton and Pitt (2002) above.

Author(s): Pitt, R., S. Chen and S. Clark
Year: 2002

Title: "Compacted urban soils effects on infiltration and bioretention stormwater control designs"
Journal (Issue): *9th International Conference on Urban Drainage, IAHR, IWA, EWRI, and ASCE, Portland, OR, September 8-13, 2002*
Study Type: Review of Previous Laboratory and Field Studies
Abstract: Prior research by Pitt (1987) examined runoff losses from paved and roofed surfaces in urban areas and showed significant losses at these surfaces during the small and moderate sized events of most interest for water quality evaluations. However, Pitt and Durrans (1995) also examined runoff and pavement seepage on highway pavements and found that very little surface runoff entered typical highway pavement. During earlier research, it was also found that disturbed urban soils do not behave as indicated by most stormwater models. Additional tests were therefore conducted to investigate detailed infiltration behavior of disturbed urban soils.
The effects of urbanization on soil structure can be extensive. Infiltration of rain water through soils can be greatly reduced, plus the benefits of infiltration and bioretention devices can be jeopardized. Basic infiltration measurements in disturbed urban soils were conducted during an EPA-sponsored project by Pitt, *et al* (1999a), along with examining hydraulic and water quality benefits of amending these soils with organic composts. Prior EPA-funded research examined the potential of groundwater contamination by infiltrating stormwater (Pitt, *et al*, 1994, 1996, and 1999b). In addition to the information obtained during these research projects, numerous student projects have also been conduced to examine other aspects of urban soils, especially more detailed tests examining soil density and infiltration during lab-scale tests, and methods and techniques to recover infiltration capacity of urban soils. This paper is a summary of this recently collected information and it is hoped that it will prove useful to both stormwater practice designers and to modelers.
Key Point(s): Same as Burton and Pitt (2002) above.

Author(s): Pitt, R., S. Chen, S.E. Clark, J. Swenson and C.K. Ong
Year: 2008
Title: "Compaction's impact on urban storm-water infiltration"
Journal (Issue): *Journal of Irrigation and Drainage Engineering*, 134(5):652-658
Study Type: Field and Laboratory
Abstract: Soil infiltration is a critical component of most urban runoff models. However, it has been well documented that, during urbanization, soils are greatly modified, especially in relation to soil density. Increased soil compaction results in soils that do not behave in a manner predicted by traditional infiltration models. Laboratory and field tests were conducted to investigate detailed infiltration behavior of disturbed urban soils for a variety of soil textures and levels of compaction. The results from traditional permeability tests on several soil groups showed that, as expected, the degree of compaction greatly affected the steady-state infiltration rate. The field tests highlighted the importance of compaction on the infiltration rate of sandy soils, with minimal effect seen from antecedent moisture conditions. For the clayey soils, however, both the compaction level and antecedent moisture conditions were important in determining the steady-state infiltration rate.
Key Point(s): The focus of the paper is on the effects of soil compaction on infiltration as part of urban development. Soil compaction has been observed as being critical in reducing infiltration rates. Knowledge of compaction rates will help to better design bioretention systems for stormwater control.

Author(s): Whalley, W.R., E. Dumitru and A.R. Dexter
Year: 1995
Title: "Biological effects of soil compaction"
Journal (Issue): *Soil & Tillage Research*, 35(1995):53-68
Study Type: Literature Review
Abstract: Compaction implies an increase in soil bulk density and associated with this are increases in soil strength, and decreases in air permeability and hydraulic conductivity. This paper considers the mechanics of compaction and then proceeds to consider the effects of that compaction on the biotic activity in the soil. The elongation of roots through soil is considered in detail and we draw attention to controversy in the literature and the current debate on the appropriateness of models based on the traditional Lockhart approach to root elongation. A model of root elongation which can be used in practice is also discussed. Soil fauna considered include earthworms, which can physically move soil and micro fauna which cannot. Consideration of microbial activity and biological interactions shows that the effect of compaction on a given soil depends on its management history. Further research is required to develop systems of agriculture which are sustainable and ecologically sound, because the effects of tillage and compaction on biological processes in the soil are only partly understood.
Key Point(s): While the focus is on agricultural systems, the general principles described provide an overview of what happens as a result of soil compaction. Primary emphasis is on the impact of compaction on plant/crop growth.