RESEARCH

Effect of urban soil compaction on infiltration rate

J.H. Gregory, M.D. Dukes, P.H. Jones, and G.L. Miller

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 inches 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.

Keywords: Compaction, cone index, double ring, infiltration, LID, low impact development, penetrometer, stormwater

Urban areas in Florida are rapidly expanding, with Florida accounting for approximately 11 percent of all new homes constructed in the United States in 2003 (U.S. Census Bureau, 2004). Soil compaction is associated with this urban development. Compaction can be the intentional compacting of a site to increase the structural strength of the soil or it can be inadvertently caused by the use of heavy equipment and grading of lots. Soil compaction affects the physical properties of soil by increasing its strength and bulk density, decreasing its porosity, and forcing a smaller distribution of pore sizes within the soil. These changes affect the way in which air and water move through the soil and the ability of roots to grow in the soil (NRCS, 2000; Richard et al., 2001).

Changes to the way that air and water move within the soil can affect infiltration rate. A decrease in infiltration rate will result in increased runoff volume, greater flooding potential and reduced groundwater recharge within watersheds. Compaction has a significant influence on soil hydraulic properties such as soil water retention, soil water diffusivity, unsaturated hydraulic conductivity and saturated hydraulic conductivity (Horton et al., 1994). These hydraulic properties in turn govern infiltration rates.

The infiltration of stormwater within urban areas is an important process being promoted as part of a new stormwater management strategy. This management strategy is often referred to as low impact development, which aims to reduce the volumes and peaks of runoff to predevelopment levels (Price George's County, 1999). Promoting infiltration is one of the primary methods for achieving this goal. The quantification of the effect of compaction on infiltration rates is therefore, an important task.

Quantifying the effect of compaction in urban areas has generally consisted of surveys that have measured infiltration rates and then related these measured infiltration rates to land development, land types, or levels of compaction. Research into the effects of soil compaction on infiltration rate has been conducted in Pennsylvania (Felton and Lull, 1963; Hamilton and Waddington, 1999), Wisconsin (Kelling and Peterson, 1975), North Carolina (Kays, 1980) and Alabama (Pitt et al., 1999). These studies have shown that soil infiltration rates are negatively affected by the compaction associated with urban development. However, these studies did not relate specific levels of compaction to infiltration rate. Although development is occurring at a rapid pace in Florida, studies have not been conducted to characterize infiltration rates as affected by compaction during development activities. It is often assumed that infiltration rate far exceeds precipitation rate due to the coarse soils found in many areas of the state. The hypothesis of this research is that compaction during typical construction practices result in a substantial reduction in infiltration rate on sandy soils.

The objectives of this research were to: 1) quantify the effect of compaction due to construction activities on infiltration rates of typical urban development sites on sandy soils in North Central Florida, and 2) determine the effect of various levels of compaction on infiltration rates of sandy urban development sites as compared to uncompacted infiltration rates.

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Materials and Methods

Compaction due to construction activities. *Site description.* A natural, mixed wood forest site in the Madera subdivision of Gainesville, Florida was chosen as a research site. Lots 2, 3, 4, 8, and 12 of the Madera development were chosen because they were undisturbed lots that had not been cleared or subjected to vehicle traffic. Lot 24 of the Madera development was chosen because it was used as an access to a detention pond and for parking heavy construction vehicles. As a result, this lot was made up of areas that had been compacted due to construction vehicle traffic next to areas that were undisturbed due to the wooded conditions. Madera lots 2, 3, 4, 8, 12, and 24 will be referred to as natural wooded lots A, B, C, D, E, and F. The soil classification for this area is a Bonneau fine sand (Arenic Paleudult; USDA, 1985) and according to data in the literature is 89.3 percent sand, 10.6 percent silt, has a field capacity of 18.9 percent by volume, and has a saturated hydraulic conductivity of 103 mm hr^{-1} in the top 23 cm (Carlisle et al., 1989).

The Mentone development of Gainesville, Florida was also chosen as a research site. The predevelopment vegetation was planted slash pine (*Pinus elliottii*), which was at least 10 years old. Compaction testing was carried out on lot 818 and lot 857. Lot 818 was chosen because it was a lot that had been partially cleared to allow access for the construction of one of the detention ponds. Lot 857 was chosen because it had been used to park heavy construction equipment and was used by construction vehicles as a shortcut between adjacent streets. Both lots were made up of areas that had been compacted and areas that were undisturbed similar to Madera lot 24 (lot F) as described previously. Mentone lots 857 and 818 will be referred to as planted forest lots G and H. The soil on lots G and H are classified as an Apopka fine sand (Grossarenic Paleudult; USDA, 1985) and according to data in the literature is 96.2 percent sand, 1.8 percent silt, has a field capacity of 11.7 percent by volume, and has a saturated hydraulic conductivity of 197 mm/hr in the top 20 cm (Carlisle et al., 1989).

Undisturbed infiltration rates. From December 2002 through February 2003, predevelopment infiltration rates were measured on wooded lots A, B, C, and E. Sixteen infiltration tests and sixteen bulk density and gravimetric soil moisture content measurements were conducted on each of these lots in areas that would eventually be landscaped after home construction. Infiltration rates were measured using a constant head double ring infiltrometer with inner and outer ring diameters of 15 cm (5.9 in) and 30 cm (11.8 in) that was inserted to a depth of approximately 10 cm (3.9 in). The constant head was maintained with a Mariotte siphon and the volume of water required to maintain this head was measured at a one-minute interval. A detailed description of the infiltration apparatus is described by Gregory et al. (2005). The infiltration tests were conducted for at least 40 min (infiltration rates were found to become constant typically within the first 10 minutes of the test or less). Cumulative infiltration was plotted against time and the data was fitted to the Philip's infiltration equation as follows,

$$I = Kt + St^{1/2} \tag{1}$$

where,

- I = cumulative infiltration depth (mm),
- K = saturated hydraulic conductivity (mm hr^{-1}),
- t = time (hr), and
- S = soil water sorptivity (mm hr^{-1}).

Values of the parameters K and S can be found by regressing the cumulative infiltration data collected in the field to Equation 1 (Lal and Vandoren, 1990). The parameter K from the Philips infiltration equation was used as an approximation for the steady state infiltration rate (Chow et al., 1988). The infiltration rates reported in this paper are the K parameter from the Philips infiltration equation.

Soil bulk density and gravimetric moisture content were measured using a standard intact core method in the top 5 cm of (2 in) soil after any decaying organic matter was removed. Volumetric moisture content was then determined as the product of the bulk density and the gravimetric moisture content (ASTM, 2002a; Blake and Hartge, 1986; ASTM, 2002b; Gardner, 1986). The cone index (ASAE, 2000) was also measured near the infiltration measurement locations using a Spectrum™ SC900 Soil Compaction Meter (Spectrum Technologies, Inc., Plainfield, Illinois), which recorded cone index in increments of 2.5 cm (1 in) up to 45 cm (17.7 in). A standard cone (ASAE, 2000) was used to determine cone index. Five cone index measurements were made near the location of each infiltrometer test.

Post development infiltration rates. Post development infiltration tests were carried out on natural wooded lot A in May 2004 since this was the only lot with a finished home during the time of this study. Infiltration rates were measured at four locations on the turf area in the front yard and four sites on the turf area in the backyard. These infiltration tests and cone index measurements were carried out using the procedure described previously.

Side-by-side testing. Infiltration, cone index, and bulk density measurements were conducted on the natural wooded lot F and the planted forest lots G and H. The testing was carried out February through July 2003. On each lot, six sites were selected for paired measurement testing. Each site consisted of a location that was undisturbed and a location that had been trafficked by construction vehicles. There was a maximum distance of 2 m (6.6 ft) between the paired measurement locations at each site. On the planted forest lot H the cone index was measured at only four of the sites due to interference of clearing operations on the other two sites. A particle size distribution analysis was conducted using the hydrometer method on five soil samples collected randomly (from the top 10 cm) on each lot (Gee and Bauder, 1986). A t-test was used to compare the paired infiltration rate and bulk density measurements.

Effects of compaction level on infiltration rates. *Site description.* An existing pasture at the University of Florida Plant Science Research and Education Unit near Citra, Florida was used for a compaction trial. The pasture area had been subjected to traffic particular to this land use for at least 20 years. This site represents pastures in Florida that are being converted to residential subdivisions and will be referred to as the pasture site in this paper. The soil has been mapped as a Candler fine sand (Lamellic Quartzipsamments; Buster, 1979), which is composed of 96.4 percent sand, 2.0 percent silt, and has a field capacity of 6.2 percent by volume in the top 25 cm (Carlisle et al., 1989).

Controlled compaction. A controlled compaction trial was carried out on the pasture site in February 2004. An area of the pasture approximately 5 m (16.4 ft) long by 2.5 m (8.2 ft) wide was cleared of the top 10 cm (3.9 in) of grass roots (a typical practice on construction sites). This area was then divided into sixteen plots each 0.6 m (2.0 ft) by 1.2 m (3.9 ft). Four levels of compaction treatments were then applied in a Latin Square experimental design. A Mikasa GX100 (MT-65H) (Mikasa Sangyo Co., Ltd.) 'jumping jack' type compactor was used to apply different levels of compaction. The compactor was moved about the plots in a steady manner to achieve a uniform level of compaction. The four levels of compaction were zero minutes of compaction (control), a half-minute of compaction, three minutes of compaction and ten minutes of compaction. Infiltration rate, bulk density, soil moisture content, and cone index were measured on each plot by methods described previously. Also, a Proctor density test (ASTM, 2002c) was conducted on a soil sample from the site. The experimental procedure was then repeated in an undisturbed area on lot D after removal of the top 10 cm (3.9 in) of organic material and soil. Thus, the two common areas being developed in North Central Florida were represented by these two sites. The results from the two locations were analyzed using the GLM procedure with an analysis of variance (ANOVA; SAS, 2001). Duncan's Multiple Range Test at the 95 percent confidence interval was used to find significant differences between the treatment means.

Vehicular compaction. A pasture area at the Plant Science Research and Education Unit was selected and a mechanical grader was used to remove the top 10 cm (3.9 in) of grass and soil from three plots each about 18 m (59.0 ft) long and 1.2 m (3.9 ft) wide. It took approximately four passes of the grader to remove the grass roots and soil and care was taken to ensure that the grader traveled in the same wheel tracks for each pass, thus ensuring that there was minimal compaction within the plots.

Three vehicles that are commonly used in urban construction were used for the vehicular compaction trial. These vehicles were an all-wheel drive Caterpillar 416B backhoe weighing 6.3 Mg (7.1 t) with a front tire pressure of 206 kPa (30 psi) and a rear tire pressure of 310 kPa (45 psi), a dump truck with a front axle weight of 6.0 Mg (6.7 t), a total load of 18.4 Mg (20.6 t) on the two rear axles and tire pressures of 310 kPa (45 psi) and a pickup truck with a front axle load of 1.1 Mg (1.2 tons), a rear axle load of 0.8 Mg (0.9 tons) and a tire pressure of 275 kPa (40 psi). Each vehicle was driven, at walking speed, along a plot with one wheel running down the middle of the plot and the other outside of the plot. Nine passes of each vehicle were made in the plots. Four measurements of infiltration rate, soil bulk density and volumetric soil moisture content as described previously were made in each wheel path.

Table 1. Predevelopment infiltration tests on the natural wooded lots (n = 16 for each lot).

Lot	A	B	C	E
	Infiltration rate (mm hr^{-1})*			
Average	634	377	582	464
Maximum	1,023	764	881	862
Minimum	329	33	261	168
CV (%)	37.7	52.0	35.7	40.8

*25.4 mm hr^{-1} = 1 in hr^{-1}

Results and Discussion

Compaction due to construction. *Activities undisturbed infiltration rates.* Infiltration tests were conducted across soil moisture conditions ranging from five to 12 percent by volume. Particle size analysis of soil samples collected on site resulted in greater than 91 percent sand, less than seven percent silt, and less than two percent clay across all samples. There was no relationship between soil moisture and infiltration rate and the testing sites were all well-drained. The infiltration rates on the undisturbed wooded lots were generally very high with average rates varying from 377 to 634 mm hr^{-1} (14.8 to 25.0 inches hr^{-1}; Table 1). These values were in the range of values reported in the literature for similar conditions (Felton and Lull, 1963; Kays, 1980; Pitt et al., 1999). The infiltration rates measured in these wooded areas were highly variable. The maximum measured infiltration rate was 1,023 mm hr^{-1} (40.2 in hr^{-1}) and the minimum measured infiltration rate was 33 mm hr^{-1} (1.3 in hr^{-1}). Table 1 shows coefficient of variation between 35.7 percent and 52.0 percent across the measurements made on individual lots.

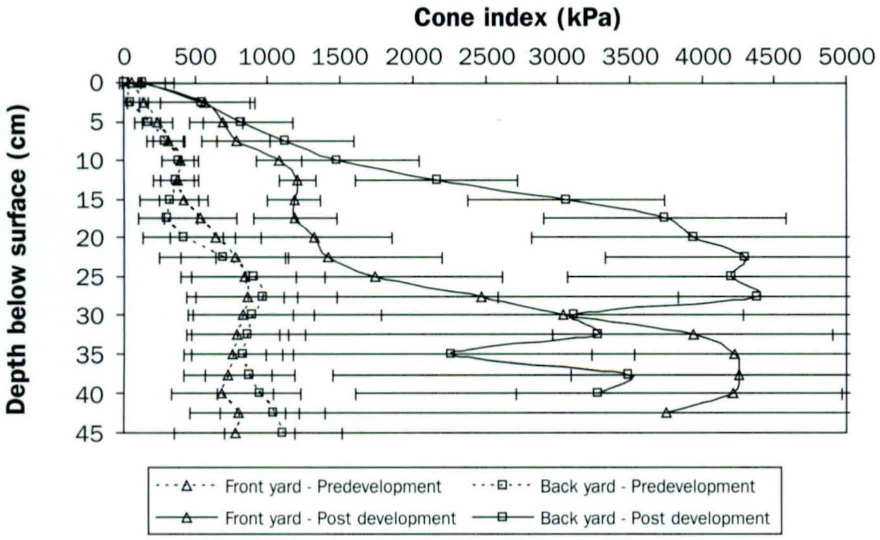
The average infiltration rates measured on the undisturbed natural wooded areas were greater than the 100-year, 24-hour design storm intensity of 254 mm hr^{-1} (10.0 in hr^{-1}) for this region in Florida (FDOT, 2003). The average infiltration rate on each lot varied from 2.5 times to 1.5 times greater than this design storm. This would indicate that, theoretically there would be no runoff from these lots for the 100-year, 24-hour design storm, and runoff would only occur if the groundwater table was to rise to the surface.

Post development infiltration rates. The post development infiltration measurements on lot A showed a reduction in infiltration rate from 861 mm hr^{-1} to 175 mm hr^{-1} (80 percent reduction) on the front yard and from 590 mm hr^{-1} to 8 mm hr^{-1} (99 percent reduction) on the backyard. The predevelopment infiltration rates were measured in approximately the same location as the post development infiltration rates. The front and back yard measurements for both the predevelopment conditions ($p = 0.037$) and post development conditions ($p = 0.026$) were statistically different. There were also significant differences between the infiltration rates for the predevelopment and post development conditions for both the front yard ($p = 0.004$) and back yard ($p = 0.007$).

Figure 1 shows predevelopment and post development mean cone index values measured on natural wooded site A. The predevelopment data for the front yard and back yard showed a maximum cone index of 858 kPa (124 psi) and 1,104 kPa (160 psi), respectively. The post development data for the front and back yard showed a maximum cone index of 4,260 kPa (620 psi) and 4,382 kPa (637 psi), respectively. This change in cone index during development of the lot was due to compaction that occurred during the construction process. The maximum cone index in the front yard occurred at 37.5 cm (14.8 in) deep while the maximum compaction on the back yard occurred at 27.5 cm (10.8 in) deep. The fill that was brought onto the front yard area, for grading purposes, resulted in this 10 cm (4.0 in) difference in depth of maximum cone index.

Side-by-side testing. Compaction from heavy construction equipment caused an overall decrease in the infiltration rate, from 733 to 178 mm hr^{-1} (28.9 to 7.0 in hr^{-1}) and a corresponding increase in bulk density, from 1.34 to 1.49 g/cm^3 (83.6 to 93.0 lb/ft^3; see Table 2). These overall changes are statistically significant for the infiltration results ($p < 0.001$) and for the overall bulk density results ($p = 0.001$). These data support the hypothesis that compaction caused by the vehicular traffic, during construction of urban developments, can result in a significantly increased bulk density and a significantly decreased infiltration rate.

Figure 1
Predevelopment and post development cone index values for natural wooded lot A, where error bars represent one standard deviation. Note that 1 inch = 2.54 cm and 1 psi = 6.89 kPa.



The natural wooded area was not subject to vehicle traffic. The planted forest would have been subjected to planting and harvesting activities involving heavy equipment that would have caused some compaction. The significant difference ($p = 0.008$) between the mean undisturbed infiltration rates on the natural wooded site (908 mm hr^{-1}; 35.7 in hr^{-1}) and the planted forest sites (631 mm hr^{-1}; 24.8 in hr^{-1}) was therefore expected; however, there was no significant difference between the undisturbed bulk densities ($p = 0.144$). The lack of a significant difference in bulk densities could be due to the soil core samples being collected in the top 10 cm (3.9 in) of the soil profile after clearing of the surface organic material. The effect of compaction is greatest at depths below 30 cm (11.8 in) (Hakansson and Petelkau, 1994); the soil samples collected in the top 10 cm (3.9 in) would not show this effect. Figure 2 shows the difference between average cone index value on the natural wooded lot and the planted forest lots. The greatest effect of compaction occurred between 25 cm (9.8 in) and 32.5 cm (12.8 in).

It is also interesting to note that after compaction there was no statistical difference ($p = 0.746$) in the infiltration rates and bulk densities measured on the natural wooded lot or those measured on the planted forest lots ($p = 0.563$). This indicates that although these sites had different undisturbed infiltration rates, compaction due to construction traffic resulted in no significant difference in infiltration rates.

From Figure 2 it should be noted that there was a difference between the magnitudes of the cone index graphs from the natural wooded lot and the planted forest lots. The natural wooded lot had maximum cone index values of 1,071 kPa (156 psi) and 1,965 kPa (286 psi) for undisturbed and disturbed area tests, respectively. On the planted forest lots, maximum cone index values were 1,914 to 3,741 kPa (279 to 545 psi) for the same respective testing conditions. This evidence supports the theory that the planted forest lot had undergone compaction in the past, which decreased the undisturbed infiltration rates compared to the natural wooded lot.

Effect of compaction level on infiltration rates. *Controlled compaction.* The results of the ANOVA conducted on infiltration rate and soil bulk density data (Figure 3), on both the pasture and wooded subplots showed that there was a significant difference between the non-compacted infiltration rates on the pasture (225 mm/hr; 8.9 inches/hr) and on the wooded area (487 mm hr^{-1}; 19.2 in hr^{-1}). However, the two locations had the same textural soil classifications (sand; 91 percent sand, less than nine percent silt, and less than four percent clay across all samples) and the same non-compacted mean bulk densities (1.49 g/cm^3; 93.0 lb/ft^3). There was no significant effect due to spatial variations in soil ($p>0.33$) within each experimental location. Statistically significant differences were not found between the mean infiltration rates of 65 mm hr^{-1} (2.6 in hr^{-1}), 30 mm hr^{-1} (1.2 in hr^{-1}) and 23 mm hr^{-1} (0.9 in hr^{-1}) that occurred after 30 second, three minutes, and 10 minutes of compaction on the pasture. This result suggests that compaction over the various levels imposed in this study did not substantially decrease the infiltration rate. Therefore, over the range of compaction that we considered, the soil was either compacted or non-compacted in terms of the effect on infiltration rate. A similar trend was observed with the data from the wooded site; however, a statistically significant difference was found between the 30-second treatment (79 mm hr^{-1}; 3.1 in hr^{-1}) and the 10-minute treatment (20 mm hr^{-1}; 0.8 in hr^{-1}).

The mean bulk densities after 10 minutes of compaction were significantly different

Table 2. Average infiltration rates, bulk density, coefficient of variation (in parentheses with units of percent) and paired t-test probability from natural wooded lot F, planted forest lots G and H (n = 6 for each lot and each compaction level except where noted).

	Mean infiltration rate (mm hr^{1})*			Bulk density (g/cm^3)†		
Lot	Undisturbed (%)	Compacted (%)	p value	Undisturbed (%)	Compacted (%)	p value
H‡	637 (22.7)	187 (52.4)	0.003	1.20 (17.2)	1.48 (5.0)	0.009
G	652 (26.9)	160 (52.0)	<0.001	1.40 (6.5)	1.52 (9.3)	0.110
F	908 (23.2)	188 (50.1)	0.001	1.42 (4.1)	1.47 (7.1)	0.252
Average	733 (28.8)	178 (49.1)	<0.001	1.34 (12.1)	1.49 (7.1)	0.001

*** 25.4 mm hr^{1} = 1 in hr^{1}**
† 1 g/cm^3 = 62.4 lb/ft^3
‡ n = 4 for compacted testing on this lot since two sites were destroyed due to land clearing.

Figure 2

Average cone index values (n = 6 for F and G; n = 4 for H) for undisturbed and compacted sites in naturally wooded areas and a planted forest, error bars represent one standard deviation. Note that 1 inch = 2.54 cm and 1 psi = 6.89 kPa.

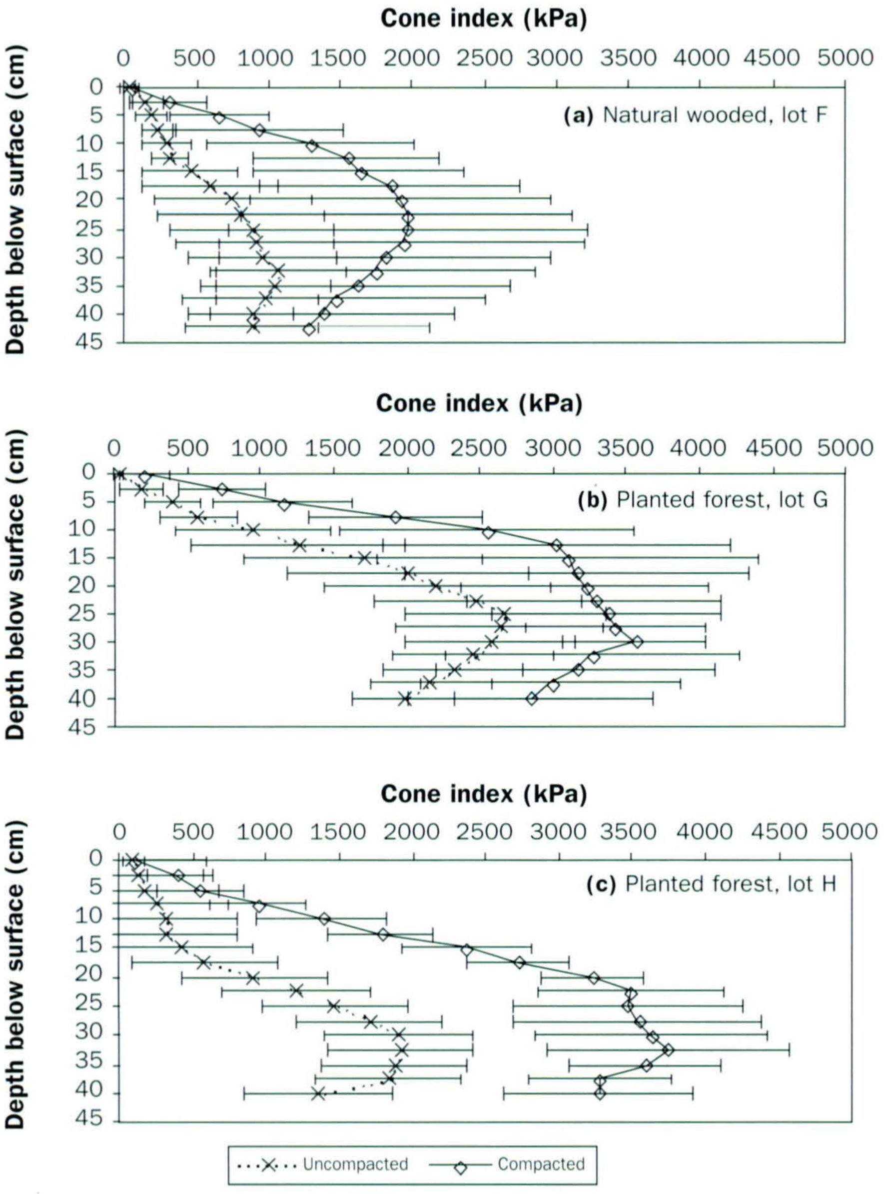


Table 3. Correlation and probability values (p) between average cone index (CI) at 2.5 cm depth increments and average surface infiltration rates, as measured on the compacted and undisturbed locations on natural wooded lot F, planted forest lot G and H.

Depth (cm)	Pearson correlation coef. (r)	p
0.0	-0.581	0.227
2.5	-0.757	0.081
5.0	-0.807	0.052
7.5	-0.804	0.054
10.0	-0.818	0.047
12.5	-0.826	0.043
15.0	-0.815	0.048
17.5	-0.817	0.047
20.0	-0.811	0.050
22.5	-0.785	0.064
25.0	-0.756	0.082
27.5	-0.753	0.084
30.0	-0.727	0.102
32.5	-0.705	0.118
35.0	-0.691	0.129
37.5	-0.675	0.141
40.0	-0.704	0.118

between the pasture and the wooded locations (Figure 3). This can be explained because the maximum Proctor density of 1.89 g/cm^3 (117.9 lb/ft^3) on the wooded site compared to the maximum Proctor density of 1.83 g/cm^3 (114.2 lb/ft^3) for the pasture, indicates that the wooded site can be compacted to a greater bulk density. The bulk density of the pasture soil after 10 minute of compaction was 1.73 g/cm^3 (108.0 lb/ft^3), this equates to approximately 95 percent of the maximum Proctor density and the bulk density of the soil at the wooded area after 10 minute of compaction was 1.79 g/cm^3 (111.7 lb/ft^3), which also equates to 95 percent of the maximum Proctor density.

The cone index throughout the profile on the non-compacted wooded area was lower than the cone index measured on the non-compacted pasture (Figure 4). The maximum average cone index on the non-compacted wooded subplots was 1,213 kPa (177 psi) at 42.5 cm (16.7 in) and the maximum average cone index on the non-compacted pasture subplots was 4,145 kPa (603 psi) at 37.5 cm (14.8 in). The pasture was subjected to compaction (caused by livestock and vehicles) in the past that probably contributed to the increased cone index. However, the difference in cone index between the pasture and the wooded site occurred at depths greater than the 10 cm (3.9 in) used for sampling bulk density. On the wooded sites, an increase in average cone index was negatively correlated with infiltration rate (Table 3). The strongest correlation occurred between 10 and 20 cm (3.9 and 7.9 in) depths ($p < 0.05$), further indicating that compaction occurs below 10 cm (3.9 in) depth.

Vehicular compaction. Table 4 summarizes the mean infiltration rates and bulk density data collected in the wheel ruts created during the vehicular compaction trial. The ANOVA indicated no significant difference between mean infiltration rates in the backhoe tracks and in the pickup tracks, although the backhoe tracks did show a numerically lower mean infiltration rate (59 mm hr^{-1}; 2.3 in hr^{-1}) than the pickup (68 mm hr^{-1}; 2.7 in hr^{-1}). Both the backhoe and pickup resulted in significantly higher mean infiltration rates than the dump truck (23 mm hr^{-1}; 0.9 in hr^{-1}).

There were no significant differences

Figure 3

Average infiltration rate and bulk density measurements (n = 4) from a pasture and naturally wooded site. Standard deviations are indicated by error bars, while means that are not significantly different (α = 0.05) are grouped by the same letter. To, To.5, T3 and T10 represent compaction treatments of 0, 0.5, 3 and 10 minutes with a portable compaction device, respectively. Note that 25.4 cm = 1 inch and 1 g/cm^3 = 62.4 lb/ft^3.

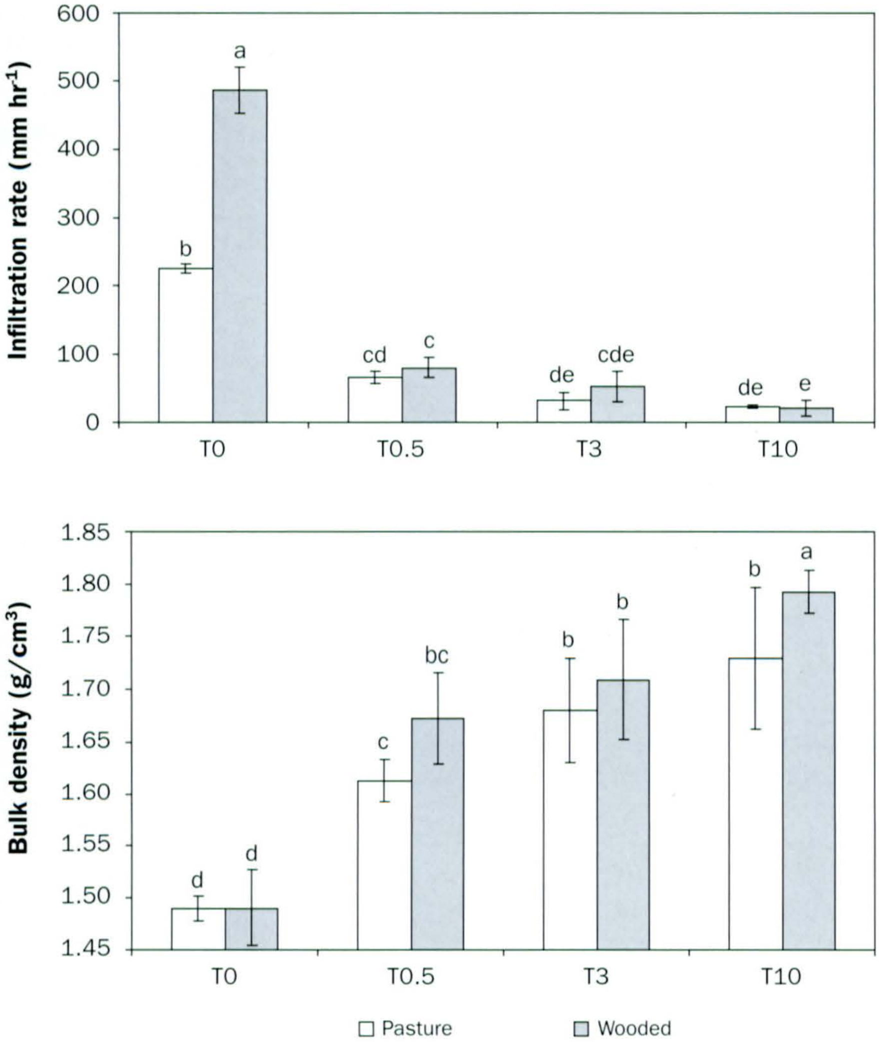


Table 4. Mean infiltration rate and bulk density result from tests conducted in the wheel ruts of a dump truck, backhoe and pickup after nine passes over a graded pasture. Means that were not significantly different were grouped with the same letter (n = 4 for each vehicle).

	Infiltration rate (mm hr^{-1})*	CV (%)‡	Bulk density (g/cm^3)†	CV (%)
Dump truck	23b	43.9	1.68a	2.3
Back hoe	59a	14.1	1.61a	1.9
Pickup	68a	23.1	1.61a	2.5

* 25.4 mm hr^{-1} = 1 inch hr^{-1}

† 1 g/cm^3 = 62.4 lb/ft^3

‡ Coefficient of variation.

between the mean bulk densities for the three treatments, although the dump truck did result in a numerically higher mean bulk density (1.68 g/cm^3; 104.8 lb/ft^3) than the backhoe and pickup (1.61 g/cm^3; 100.5 lb/ft^3). The lack of a significant difference between the mean bulk densities, again may be due to the bulk density being determined from soil samples collected in the top 10 cm (3.9 in) of the soil profile, since compaction tends to occur below 10 cm (3.9 in) as has been shown previously.

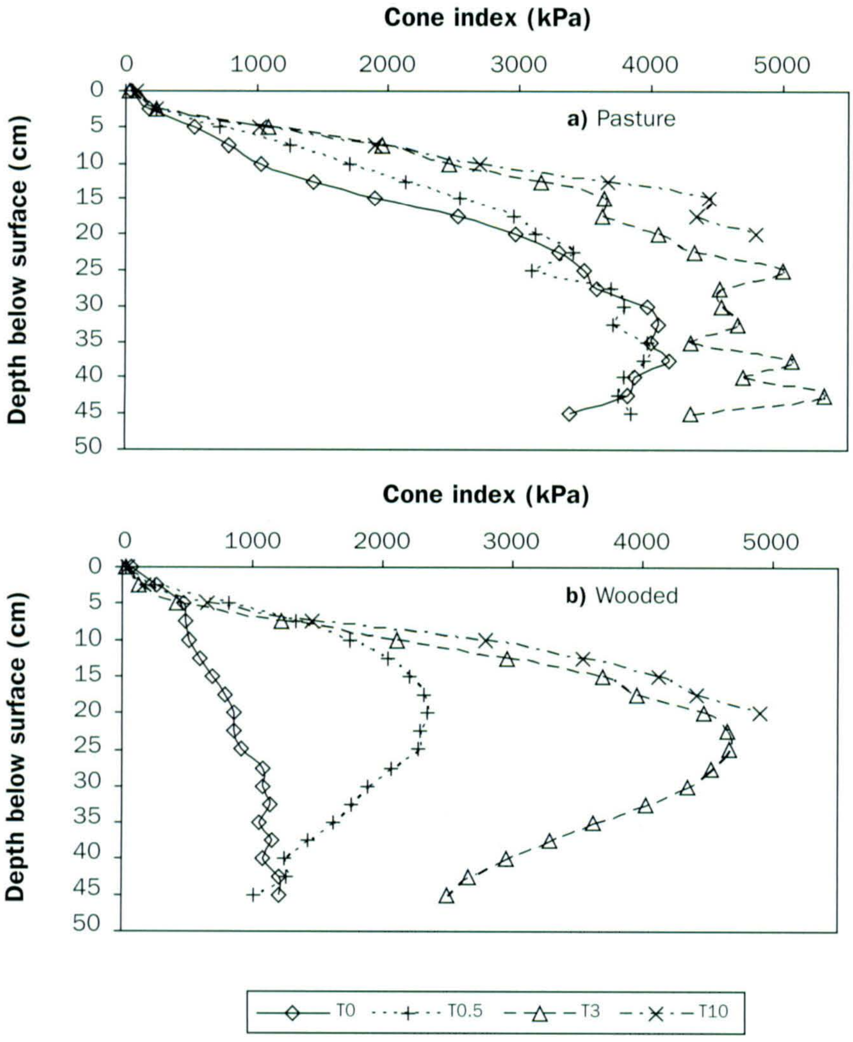
Summary and Conclusion

Soil compaction was shown to have a negative effect on infiltration rates of soils in north central Florida. On these sandy soils, the lowest level of compaction resulted in significantly lower infiltration rates; therefore, any amount of compaction must be avoided on these soils if runoff from development sites is to be minimized. However, it was shown that there could be a significant difference between the effect of compaction caused by relatively light construction equipment (i.e. a backhoe and pickup) and very heavy equipment (i.e. a fully loaded dump truck). For the purposes of determining potential infiltration rates, soils could be classified as either compacted or non-compacted. This classification of the compaction of a soil could have a significant affect on hydrological and stormwater modeling, particularly for low impact development projects where the soil infiltration rates are critical since infiltration is a key component of the stormwater network. Accurate infiltration rate information is also important in traditional runoff estimation from urban areas because undisturbed soil infiltration rates are typically assumed for pervious areas. Overestimation of the soil infiltration rate would result in an underestimation of the runoff from a specified area and a resultant underestimation of a flooding event.

To maintain predevelopment infiltration rates on a lot, areas of the development should be left undisturbed. Demarcating areas of the development to prevent compaction of the soil would help maintain predevelopment infiltration rates. Special efforts should also be made to leave natural areas, undisturbed as these areas were shown to have the highest infiltration rates. Reducing the use of any equipment on the lot as much as possible would also help limit the reduction in infiltration rates caused by compaction.

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

Figure 4
Average cone index values for each level of compaction (n = 4) at the pasture and the wooded sites. T0, T0.5, T3 and T10 represent compaction treatments of 0, 0.5, 3 and 10 minutes with a portable compaction device, respectively. Note that 1 inch = 2.54 cm and 1 psi = 6.89 kPa.



a development that have been exposed to compaction and are thus contributing to decreased infiltration rates.

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Soil carbon pools in central Texas: Prairies, restored grasslands, and croplands

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ABSTRACT: Establishment of perennial grasses on degraded soils has been suggested as a means to improve soil quality and sequester carbon in the soil. Particulate organic carbon may be an important component in the increased soil carbon content. We measured particulate organic carbon [defined as organic carbon in the 53 to 2000 μm (0.002 to 0.08 in) size fraction] and mineral associated organic carbon (defined as the less than 53 μm (0.002 in) size fraction) at three locations in central Texas. Each location had a never-tilled native grassland site, a long-term agricultural site and a restored grassland on a previously tilled site. Organic carbon pool sizes varied in the surface 40 cm (16 in) of native grassland, restored grasslands and agricultural soils. The native grasslands contained the largest amounts of total organic carbon, while the restored grasslands and agricultural soils contained similar amounts of total organic carbon. Both particulate organic carbon and mineral associated carbon pools were reduced beyond the depth of tillage in the restored grass and agricultural soils compared to the native grassland soils. The restored grassland soils had a larger particulate organic carbon content than the agricultural soils, but the increase in particulate organic carbon was limited to the surface 5 cm (2 in) of soil. Trends in particulate organic carbon accumulation over time from nine to 30 years were not significant in this study.

Keywords: Particulate organic carbon (POC), native grassland, soil quality, mineral associated carbon (MAC), total organic carbon (TOC)

Soil organic matter is a heterogeneous mixture of organic substances that has an important role in determining soil productivity. For modeling purposes, it has been beneficial to separate soil organic matter into separate pools that have different functions and degradation rates in the soil. However, in practice, it has been difficult to separate soil organic matter into pools similar to the conceptual pools proposed by the modeling community. Techniques developed to isolate soil organic matter pools include chemical, densiometry, and size fractionation methods. Cambardella and Elliott (1992) developed a technique based upon size fractionation that isolates the organic size fraction between 52 to 2000 μm (0.002 to 0.08 in), which they called particulate organic matter. The particulate organic matter pool has been related to nutrient mineralization (N, Parry et al., 2000; and P, Salas et al., 2003), vegetation type (forest, Barrios et al., 1997; and crop, Bremer et al., 1995), soil carbon content under various tillage practices (Needelman et al., 1999; Wander and Bidart, 2000), and soil quality changes (Franzluebbers and Arshad, 1997; Wander et al., 1998; Chan, 1997).

The particulate organic matter fraction, of which the carbon content is referred to as the particulate organic carbon, appears to be more sensitive to changes in management practices than total organic carbon (Cambardella and Elliott, 1992; Needelman et al., 1999; Wander and Bidart, 2000; Bowman et al., 1999). Particulate organic carbon content often changes more rapidly than the total organic carbon content with a change in management. This difference may be a result of differential decomposition rates under various management and climatic conditions

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