

# THE USE OF SURFACE TREATMENTS FOR THE PREVENTION OF SOIL COMPACTION DURING SITE CONSTRUCTION

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**Abstract.** Urban soils are commonly compacted during site construction, leading to alterations in soil structure that are detrimental to plant health. In a study of California residential developments, construction processes and their associated impacts were found to vary among developments. On mass-graded sites, characterized by grading and compaction of the entire construction site with equipment specifically designed for that purpose, bulk density analysis revealed that compaction is uniformly severe. On selectively graded sites compaction was caused mainly by general construction equipment, vehicles and storage of construction materials. Bulk densities of undisturbed (fenced) areas were significantly lower than disturbed areas on these selectively graded sites. On these sites, several techniques can be used for the prevention of soil compaction, including the use of surface treatments. The effectiveness of plywood, mulch, and gravel as surface protective treatments was evaluated on a study site utilizing a front-end loader to simulate construction impacts. While plywood did not reduce compaction, bulk densities under mulch and gravel treatments were significantly lower than the un-protected control. When used in combination with other techniques, some surface treatments are useful tools for reducing soil compaction during site construction.

Urban soils are routinely compacted during the site construction process. During road building and sidewalk and foundation installation, the use of specialized equipment is required to compact soils to specified levels. The frequent traversing of other construction vehicles over the site during the construction process as well as the storage of building materials on the site also compacts these soils. Following completion of construction, much of the land is converted to landscape.

The construction process destroys the existing soil structure and resorts soil particles into a more compact arrangement, thereby increasing soil density. These changes in soil density decrease soil porosity, reduce the permeability of the soil, and increase soil strength, thereby limiting root

growth and function (3). Ultimately, these soil changes limit tree growth and may lead to subsequent dieback and decline (12).

It is important to have a precise way to evaluate the severity of compaction that has occurred on a soil prior to landscape installation. Bulk density is commonly considered the most direct measure of soil compaction (2). It is defined as the dry weight of soil per unit volume, usually reported in  $Mg/m^3$ . For any given soil there is a bulk density above which plant growth is severely limited (5). Previous studies have shown that urban soils commonly have densities higher than these limiting values (4,15). Soil compaction then, can be one of the most significant health problems for trees growing in urban areas.

Strategies to resolve soil compaction problems can be classified as either preventative or ameliorative. In soils compacted to levels detrimental to plant health, amelioration is often attempted. Prior to planting, compacted soils have been deep plowed or subsoiled, benefiting soil physical properties (13) as well as plant growth and yield (8,9). However, the effects of these treatments may be short lived (2,3,9). The use of these techniques in urban areas is limited due to their cost, the size of equipment needed in the context of the limited space in urban areas, and the technique's dependence upon a specific soil moisture level. Compacted soil may also be completely replaced or heavily amended (10), but the cost of materials and labor may be prohibitive.

For existing trees, other techniques have been suggested for improving growing conditions in compacted soils. Treatments with compressed air

(16) provided only temporary, localized soil improvement. Similarly, Pittenger and Stamen (11) determined that augering, water jetting, or installation of perforated pipe provided no benefit to trees growing on compacted soils. Watson (17) describes a technique of trenching radially from tree trunks and backfilling with a mixture of soil and compost. He has observed increased root growth in these channels.

Due to the lack of cost-effective, long term mitigation strategies for compacted soils, prevention of soil compaction is the most desirable strategy. One of the more common preventative approaches has been the use of surface protective treatments such as mulch, plywood, steel plates, or a gravel and geotextile fabric combination (3,6,7). The effectiveness of these treatments prior to this study has not been evaluated.

The objectives of this study were twofold. The first was to evaluate the causes and severity of soil compaction during site construction and to outline where arborists and others might intervene in the construction sequence to minimize soil compaction. The second objective was to assess the effectiveness of different surface treatments for reducing or preventing soil compaction.

### **Causes and Severity of Soil Compaction**

Two distinct types of construction methods were observed by the authors among residential developments in Northern California. The first method is referred to as mass grading. This is characterized by rough grading followed by compaction with sheep's-foot rollers or other devices throughout the entire development site. Homes were then built atop concrete slab foundations. Through bulk density analysis of one of these sites (Northstar, Davis, CA), it was determined that all of the silty clay loam soil on this site was severely compacted before the foundations were laid. Bulk densities at this stage of the construction sequence ranged from 1.63 to 1.82 Mg/m<sup>3</sup>, much higher than the 1.40 Mg/m<sup>3</sup> critically limiting bulk density previously cited for a soil of this texture (5). Preventing soil compaction on these sites would involve limiting the grading process, a considerable change in construction method. For this reason, preventing soil compaction on these mass graded sites is

not feasible, and ameliorating these soils becomes a necessity for satisfactory plant growth.

The other type of construction method was identified as selective grading. In these developments only certain portions of the site (roadways and some foundations) are graded. Individual lots are often not graded at all. This method is often associated with sites having existing trees or slopes that preclude mass grading. At one of these sites (Briggs Ranch, Folsom, CA), significant increases in soil bulk density were found in both the graded and ungraded portions of residential lots. Backhoes and front end loaders were the most common equipment found on these sites, creating the most severe compaction due to their weight. Bulk densities in the fenced (undisturbed) areas ranged from 1.05 to 1.42 Mg/m<sup>3</sup>, while in unfenced areas, bulk densities of 1.56 to 1.90 Mg/m<sup>3</sup> were found; often exceeding the 1.60 Mg/m<sup>3</sup> critical bulk density for the loam soils on the study sites (5).

### **Effectiveness of Surface Treatment Materials**

**Materials and methods.** A fallow agricultural field, cultivated yearly and located in Davis, CA was divided into thirty five plots. Each plot was divided into six soil sampling areas of equal size. Soil texture, determined by hydrometer analysis (DANR Laboratory, University of California, Davis), was a silt loam. Initial soil bulk density was determined as the average of two samples per plot at 0-10 cm depth utilizing a 5.1 cm diameter, 10.2 cm deep core sampler (AMS, American Falls, Idaho). Bulk densities were also established at 13-23 cm and 25-36 cm depths adjacent to the plots at 5 locations so as not to disturb soils in the plots with the large holes required for sampling at depth. The following treatments were replicated 5 times and installed by hand on April 19, 1993: 1) 15 cm of mulch consisting of shredded tree trimmings including leaves, bark and wood with particles of 2-10 cm, 2) 15 cm of mulch layered over a geotextile fabric (Trevira Spunbond Type 1125, Hoechst Celanese, Spartanburg, S.C.), 3) 15 cm of mulch layered over a plastic grid (Tensor Geogrid BX-1100, Tensor Corporation, Morrow, GA), 4) 10 cm of gravel (3/4" crushed), 5) 10 cm of gravel on top of a geotextile fabric, 6) 1.9 cm (3/4 in) thick

construction-grade plywood, and 7) an unprotected control.

The field was irrigated in an attempt to achieve an optimal soil moisture level at which maximum compaction would occur, determined as 17% by proctor analysis, a laboratory test which simulates field compaction at various moisture contents (1). Soil moisture averaged 23% on the day that a front-end loader (Case 480 LL Construction King) weighing approximately 13,000 pounds with 17.5L-24 rear and 11L-16 front tires inflated to 35 psi was run across the treatments. The loader was driven across the field in a controlled pattern, representing 8 passes of the vehicle over the entire site.

Following compaction, bulk density was established at two locations within each of the 35 plots at the 0-10 cm depth with a core sampler as discussed above. Bulk density of soils at 13-23 cm and 25-36 cm depth was obtained in the unprotected plots as described for soils at the 0-10 cm depth. All samples were taken near the center of the plots.

**Results and discussion.** In the unprotected plots, front end loader traffic increased surface (0-10 cm) bulk densities significantly from 1.42 to 1.59 Mg/m<sup>3</sup>. At 13-23 cm and 25-36 cm depths, bulk densities increased from 1.54 to 1.58 Mg/m<sup>3</sup> and 1.48 to 1.51 Mg/m<sup>3</sup> respectively. However, bulk densities increases below the 10 cm depth were not statistically significant (see Table 1). These results concur with the general knowledge that vehicular traffic compacts soils most severely near the surface (2).

**Table 1. Bulk density of unprotected soil before and after compaction by a front-end loader. Values are the average of 2 samples from each plot and 5 replicate plots.**

Depth	Pre-compaction Mg/m <sup>3</sup>	Post-compaction Mg/m <sup>3</sup>
0-10 cm	1.42	1.59*
13-23 cm	1.54	1.58
25-36 cm	1.48	1.51

\* = significance to the 5% level, ANOVA.

All surface treatments with the exception of

plywood reduced soil compaction at the 0-10 cm depth when compared with the unprotected plots. Bulk densities between 1.50 and 1.51 Mg/m<sup>3</sup> were found under the mulch, gravel, mulch/geotextile, mulch/grid, and gravel/geotextile treatments. In contrast, densities under plywood averaged 1.55 Mg/m<sup>3</sup>, which was not significantly different from the 1.59 Mg/m<sup>3</sup> found in unprotected plots (Table 2).

The data indicate that a front-end loader, a typical piece of equipment found on selectively graded sites can significantly increase soil bulk densities of surface soils. Utilizing appropriate surface protective treatments may reduce soil compaction from these vehicles on these sites.

Successfully preventing soil compaction during construction requires an integrated approach which begins during the conceptual stages of a project and involves all members of the development team including the arborist and/or horticultural consultant. During the planning stages, these professionals should work with the developer (and/or planner, designer, contractor) to encourage as little grading as possible on a site to reduce the compaction that is necessary during cut and fill operations. By utilizing discontinuous foundations, which are composed of stem walls and piers, grading is not required on most sites, in contrast to the grading and compaction required as preparation for concrete slab foundations. In addition, to minimize compaction in tree root zones, foundations, roads and other infrastructure should be

**Table 2. Bulk densities following compaction under surface protective treatments. Values are the average of 2 samples from each plot and 5 replicate plots.**

Treatment	Density (Mg/m <sup>3</sup> )
Mulch	1.51 a*
Gravel	1.50 a
Mulch/Geotextile	1.51 a
Mulch/Grid	1.50 a
Plywood	1.55 ab
Unprotected	1.59 b

\*Values followed by the same letter are not statistically different from one another, ANOVA.

located as far away from existing trees as possible. Ideally, tree root zones should be fenced throughout the entire construction process to avoid soil compaction in these sensitive areas.

In unfenced, non-graded areas, a surface protective treatment should be used to reduce soil compaction from construction impacts. Mulch is the most practical of all of the treatments which were evaluated, as it is easy to install, inexpensive, recycled, and may be utilized in new landscapes after construction is complete. A 15 cm layer of mulch is recommended for this purpose, although a thicker layer may be more effective. After construction is complete, the mulch layer may need to be partially removed if the thickness and or density of this layer is such that oxygen or water movement is hindered, although previous studies have shown no detrimental effects from coarse mulches 18 inches thick (18). The application of surface treatments should similarly provide compaction protection from humans or vehicle traffic after construction and landscape installation is completed.

It is important to keep in mind that surface treatments reduce but do not eliminate soil compaction. Successful soil compaction prevention requires a multi-faceted approach. Compaction may be minimized by selecting light weight equipment with wide, smooth, low pressure tires; directing traffic routes away from designated landscape areas; and limiting equipment use to periods when the soil is relatively dry (6). Fencing is also used to keep construction vehicles and materials away from designated landscape areas (14). By specifying the minimum degree of compaction necessary for fill areas, compaction may also be reduced (6). Compaction may also be lessened by avoiding soil work when soils are moist and more susceptible to compaction (3).

## Conclusion

Surface protective treatments such as mulch can be used as a tool for the prevention of soil compaction on selectively graded sites. Successful prevention of soil compaction requires an integrated approach and a thorough understanding of the construction sequence unique to a site.

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## Literature Cited

1. Al-Khafaji, A. and Andersland, O., 1992. Geotechnical Engineering and Soil Testing. Saunders College Publishing, Fort Worth, TX, 695 p.
2. Chancellor, W., 1977. Compaction of soil by agricultural equipment. University of California Div. Ag. Sci. Bulletin 1881, 53 p.
3. Craul, P., 1992. Urban Soil in Landscape Design. John Wiley and Sons, Inc. New York, USA, 396 p.
4. Craul, P. and Klein, C., 1980. *Characterization of streetside soils in Syracuse, New York*. Metro. Tree Impr. Alliance (METRIA) Proc. 3:88-101.
5. Daddow, R.L. and Warrington, G.E. 1983. Growth limiting soil bulk densities as influenced by soil texture. US Forest Service, WSDG Report, WSDG-TN-00005, 17 p.
6. Matheny, N. 1989. A Technical Guide to Community and Urban Forestry in Washington, Oregon and California. World Forestry Center.
7. Miller, N., Rathke, D. and Johnson, G., 1993. Protecting trees from construction damage. Minnesota Extension Service. 13pp.
8. Morris, L., 1988. *Influence of site preparation on soil conditions affecting stand establishment and tree growth*. Southern Journal of Applied Forestry 12(3):170-178.
9. Oster, J., Singer, M., Fulton, A., Richardson, W. and Prichard, T., 1992. Water Penetration Problems in California Soils. Kearny Foundation of Soil Science. 165 pp.
10. Patterson, J., 1977. *Soil compaction-effects on urban vegetation*. J. Arboric. 3(9):161-167.
11. Pittenger, D. and Stamen, T., 1990. *Effectiveness of methods used to reduce harmful effects of compacted soil around landscape trees*. J. Arboric. 16(3):55-57.
12. Ruark, G., Mader, D. and Tattar, T., 1982. *The influence of soil compaction and aeration on the root growth and vigour of trees-A literature review. Part 1*. Arboricultural Journal 6:251-265.
13. Rolf, K., 1991. *Soil improvement and increased growth response from subsoil cultivation*. J. Arboric. 17(7):200-204.
14. Schoeneweiss, D., 1982. *Prevention and treatment of construction damage to shade trees*. J. Arboric. 8(7):169-174.
15. Short, J., Fanning, D., McIntosh, J., Foss, E. and Patterson, J., 1986. *Soils of the mall in Washington, DC: I. Statistical summary of properties*. Soil Science Society of America Journal. 50:699-705.
16. Smiley, T., Watson, G., Fraedrich, B. and Booth, D., 1990. *Evaluation of soil aeration equipment*. J. Arboric. 16(5):118-123.
17. Watson, 1990. *Tree growth revisited*. Golf Course Management 58(6).
18. Watson, G.W. and Kupkowski, G., 1991. *Effects of a deep layer of mulch on the soil environment and tree root growth*. J. Arboric. 17(9):242-245.

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**Résumé.** Les procédures de construction et les impacts associés varient entre les différents projets. Sur les sites de rehaussement de «masse», caractérisés par une élévation du niveau du terrain en construction et une compaction du sol par de l'équipement lourd spécifiquement conçu à cet effet, l'analyse de la densité du sol révélait que la compaction était sévère et uniforme. Sur d'autres sites en construction où un rehaussement «sélectif» a été effectué, par opposition à un rehaussement de masse, la compaction était généralement provoquée par l'équipement normalement utilisé pour la construction et les véhicules ainsi que par l'entreposage des matériaux de construction sur le site. La comparaison entre des superficies non bouleversées — protégées au moyen de clôtures — et celles bouleversées révélait un accroissement drastique de la densité du sol relié à ces impacts. L'efficacité des panneaux de contreplaqués, des paillis de copeaux de bois et de la pierre concassée employés à titre de surface de protection du sol était évaluée. Tandis que l'emploi des panneaux de contreplaqués ne réduisait en rien la compaction du sol, la densité du sol sous des surfaces recouvertes de paillis ou de gravier était significativement plus faible que celle de la surface contrôlée sans protection. L'emploi de membranes renforcées ou de treillis de plastique était sans effet positif.

**Zusammenfassung.** Baumaßnahmen und deren Auswirkungen variierten während des Bauablaufs. Bei 'Massenaushub'-Baustellen, dadurch charakterisiert, daß Abgrabungen und Verdichtungen auf der ganzen Baustelle entstehen durch spezielle Baugerätschaft, die für diesen Einsatz geschaffen wurden ergibt eine Analyse der Bodenkörperdichte schwere und gleichförmige Verdichtung. Auf anderen Baustellen, wo selektiver Abtrag stattfand im Vergleich zu einer Massenabtragung, wurde eine Verdichtung nur durch gewöhnliche Baugerätschaften, Fahrzeuge und der Lagerung von Baumaterialien auf der Baustelle verursacht. Vergleiche zwischen ungestörten (umzäunten) und gestörten Bereichen in Beziehung gesetzt zu obigen Einflüssen ergaben drastische Anstiege in der Bodenkörperdichte. Die Effektivität von Sperrholz, Mulch und Schotter als Oberflächenschutzmaßnahme wurde ermittelt. Während Sperrholz die Verdichtung nicht reduzieren konnte, ergab doch der Einsatz von Mulch und Schotter eine wesentlich niedrigere Körperdichte als auf der ungeschützten Kontrollfläche. Der Gebrauch von