A REVIEW OF THE EFFECTS OF SOIL COMPACTION AND AMELIORATION TREATMENTS ON LANDSCAPE TREES

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Abstract. Compacted soil is a frequently encountered problem on urban and community landscape sites. Numerous site amelioration methods and planting techniques have been employed to counteract the harmful effects of soil compaction on plant establishment and growth. Recent research aimed at examining the effectiveness of these techniques has given mixed results. It is evident that compaction restricts woody plant growth, but the nature and causes of the restriction are not completely understood. This is partly a result of the difficulty in separating the effects of interrelated factors such as physical impedance to roots, soil gas exchange, water infiltration and drainage. Consequently, it is difficult to prescribe with confidence techniques to improve compacted soil conditions for landscape trees. A review of our current understanding of soil compaction and its amelioration is presented here from the perspective of woody plant establishment.

Index words: bulk density, penetrometer, soil aeration, urban horticulture

Well-grown landscape trees are recognized as one of a city's greatest assets. Unfortunately, growing trees successfully in the modern urban environment is extremely problematic. A large number of trees do not survive their first two years, and the average street tree lifespan in city neighborhoods has been estimated to be only 10 years (14). One of the primary reasons for this poor survival rate is the adverse rooting environment provided by many urban sites (9). Trees can encounter similar difficulties, however, even far from urban areas. Although some urban stresses, such as vandalism, may not be common in such areas, rooting restrictions may be equally severe. Landscape plantings are most often around buildings, especially newly constructed ones, where subsoil and fill are often mixed and compacted by heavy construction traffic and covered with a cosmetic layer of topsoil (1).

Compaction in Urban Areas and Around New Construction

Urban sites often have limited rooting space, compacted soil (or poor soil structure and texture that will eventually lead to compaction), restricted aeration, poor drainage, crusting on bare soil, and excessive soil variability resulting from frequent disturbance and buried debris (9). Many of these characteristics, such as aeration, drainage and restricted rooting space, are related to soil compaction. Compaction levels in urban areas and around new construction are often extreme. In a study on the Mall in Washington D.C., Patterson found the park's clayey soil to be extremely compacted with bulk densities from 1.7 to 2.2 g/cm^3 (30). In a survey of areas to be landscaped near new residential and commercial construction, mean soil bulk density was found to be 1.56 g/cm^3, a 0.5 g/cm^3 increase over adjacent undisturbed areas (1). These levels of compaction restrict root growth for many woody species (6,29,48).

Compaction and Root Growth

Compacted soil restricts rooting area, slows or halts root penetration, and results in increased branching and radial thickening of roots (25). Rooting space for landscape trees is often already restricted, especially where trees are placed in tree pits, narrow parkways or above-ground planters. Compacted soil, however, creates an additional, more immediate space limitation as roots are unable to penetrate dense soils encountered beyond the planting hole. Compaction also appears to decrease tree establishment (13,47), dramatically reduce shoot growth (6) and is indi-

cated as a primary factor in sugar maple decline in urban areas (33). Establishing a critical compaction level for woody plant growth would consequently be extremely useful. Compaction level is generally characterized by soil bulk density (oven dry mass/volume) or by resistance to penetration as determined with a penetrometer.

There appears to be some variation among species in their ability to penetrate compacted soil of a given bulk density. Root growth of Forsythia ovata 'Nakai' was significantly restricted at bulk densities as low as 1.21 g/cm^3 (1). In a container experiment, sugar maple (Acer saccharum) seedling roots were evenly distributed throughout the pot for uncompacted sandy loam soil but were increasingly confined to the upper portion as bulk density increased. At bulk densities of 1.40 g/cm^3 and above, roots were few and entirely confined to the upper third of the pot (6). Rooting can therefore be greatly restricted by even moderate soil compaction. Some of the variation among species, however, may be due to differing soil textures. Zisa found that depth of root penetration for Austrian pine (Pinus nigra) in a sandy loam soil was not statistically reduced until bulk densities reached 1.6 g/cm^3, but a bulk density of only 1.4 g/cm^3 severely restricted the same species in a silt loam. This large variation in restricting bulk densities has been attributed in part to the interaction of bulk density and soil texture (29,48). Tap root growth of Tree of Heaven (Ailanthus altissima) was considerably more restricted by a sandy loam soil with a bulk density of 1.64 g/cm^3 than by a mason sand with bulk density of 1.67 g/cm^3 (29). Some have suggested making adjustments to critical bulk densities based on soil texture (32,42), with sandier soils having a higher critical bulk density for root growth than finer textured soils, but this idea has not been experimentally developed to a useful degree. The great variation, in any case, makes bulk density difficult to use as a predictor of plant response.

Penetrometer measurements have been used extensively to quantify soil resistance to penetration in crop research, but these measurements are infrequently made in woody plant research. A metal shaft with a cone-like tip is pushed into the soil and a reading of the force required is re-corded. The resistance encountered, however, varies with cone design, application of lubrication and method of forcing into the soil (43). These difficulties can be largely overcome, however, by equipment standardization. Since the late 1960s, the American Society of Agricultural Engineers has had standards in place for penetrometer design. Cones with 30° tips and diameter sizes of 12.8 and 20.3 mm are standard. The smaller cone size is for use in harder (more resistant) soils (2). Consistent use of these standards will allow for more meaningful comparisons between studies. Penetrometer measurements already take into account soil type and moisture level interaction to some degree. A clay soil that is completely impenetrable when dry can be very easily penetrated when saturated. This may be true to a much lesser degree for a sandy soil. Penetrometer resistance has been more strongly correlated to plant performance than bulk density (39,40). Unless moisture levels are kept constant (as in a controlled laboratory experiment) measurements must be taken over a range of moisture levels in order to make comparisons between sites.

For row crops, a resistance of 2 MPa is generally considered to be critically restricting to plant growth (25). Research on woody plants is scarce, but a reasonable estimate of a critically restricting level may be made from agronomic studies and the little woody plant research available. In a study of 22 species, dicots were better able to penetrate extremely compacted soil than were monocots (25). Since a large number of crop species are monocots, this suggests that the critical level for woody species may be somewhat higher than 2 MPa. In cotton, (Gossypium hirsutum) a woody dicot, root penetration was significantly restricted at 2.5 MPa and totally halted at 3.0 MPa in a sandy loam soil (38). As a flat-bottomed penetrometer was used, however, these values may be expected to be slightly higher than if a standard 30° cone had been used. Height of Terminalia brassii trees was restricted in logging areas with a resistance of 2.0 - 2.3 MPa and above when compared with less compacted areas. However, removal of topsoil and consequent low nutrient availability may have contributed to growth reduction in some areas (27). It seems plausible to suggest 2.3 MPa as an

approximate critical limit for soil strength when measured with a standard penetrometer, above which root growth of woody species would be severely restricted.

Compaction and Shoot Growth

Shoot growth has also been shown to be adversely affected by soil compaction (1,6,29). If root growth is restricted by compacted soil, then the smaller volume of soil exploited by roots would result in a smaller water reservoir available to the plant. It is consequently difficult to separate the effects of water stress and mechanical impedance on shoot growth. Some studies, however, indicate that the effect of root restriction on shoot growth is independent of water supply (22,26). Planting soybeans in smaller pots resulted in much reduced shoot growth even when pots were watered several times a day (22). However, restricted rooting area could conceivably result in a reduction of total root surface area. Thus, total water uptake could have been reduced even when plants were well irrigated. A similar result might occur where rooting area is restricted by compacted soil. The relationship between water uptake and compaction effects on roots physiology and morphology, however, merits further study.

It has been suggested that shoot reduction in response to mechanical impedance could be a result of an alteration in the production of root-synthesized hormones such as gibberellins and cytokinins (23). There is, however, no experimental evidence showing such a relationship. An increase in ethylene production has been demonstrated in roots encountering mechanical impedance. This increase was shown to increase root diameter in beans, but effects on shoot growth were not observed (21). However, a buildup of ethylene in rooted cuttings has been shown to prevent bud break in roses (35).

Compaction reduced stomatal conductance and increased xylem sap ABA levels in maize, but these effects disappeared after plots were irrigated (37). Soil strength would have decreased when soil moisture increased (39), thus reducing the mechanical impedance encountered by roots. However, because root tips were believed to have reached non-restricting zones in the soil, Tardieu

et. al. (37) attributed the increased stomatal conductance to improved water relations and not to reduced soil strength resulting from irrigation. Thus any hormonal signals to shoots were only indirectly related to mechanical impedance.

Compaction and Soil Aeration

Poor aeration has also been considered a principal result of compacted soil. In the compaction process, macropores are compressed, resulting in a larger volume of micropores through which air and water move slowly (17). Low soil air oxygen levels restrict root growth. In an experiment with avocado trees, Valoras found root growth stopped when oxygen diffusion rates (ODR) dropped below .20 $\mu g/cm^2/min$ (41). ODR measures the rate that oxygen diffuses to a wire electrode that acts as a sink. ODR levels limiting to plant growth have been described by Erickson as follows: "at ODRs below .2 $\mu g/cm^2/min$ plant roots will not grow, plants are severely stressed and may die; between .2 and .4 $\mu g/cm^2/min$ the plants are retarded and above .4 $\mu g/cm^2/min$ plants grow normally" (12). These values agree with Valoras' findings. Valoras obtained the ODR level of .2 $\mu g/cm2/min$ when an air stream of 2% oxygen or less was supplied to the soil. Treatments with 10% oxygen did not reduce avocado root growth significantly. Containerized white oaks (Quercus alba), tuliptrees (Liriodendron tulipifera), sugar maples (Acer saccharum), American elms (Ulmus americana) and Moraine honeylocust trees (Gleditsia triacanthos inermis 'Moraine') showed no signs of damage when their media was sealed with paraffin for 3 weeks (45). Oxygen levels initially dropped to 1%. However, oxygen was not monitored, and it is not known whether soil oxygen remained at this low level throughout the experiment. When flooded, all species with the exception of American elm dropped their leaves and died after a similar period. It is notable that American elm survived after more than 8 weeks of flooding. Of all species only elm produced adventitious roots. These were found to take up water while submerged (45).

Plant response to oxygen level, however, has been shown to interact with mechanical impedance (15). Consequently, the critical oxygen level

in compacted soils may be higher than in uncompacted soils. At a bulk density of 1.3 g/cm^3, cotton root penetration was restricted when oxygen levels were reduced to 5%. At a density of 1.5 g/cm3, however, root restriction began at 10% oxygen. At extreme bulk densities (1.9 g/cm^3), the effect of mechanical impedance dominated, and root growth was restricted equally at all oxygen levels (36). In moderately compacted soils, therefore, limiting oxygen levels may have a more severe effect than in uncompacted soils.

A general critical oxygen level for all woody species cannot be characterized. Not only is there considerable range among species in their tolerance of anoxia, but other growing conditions appear to decidedly affect oxygen requirements. Consequently, a critical oxygen level cannot be considered in isolation. It seems reasonable, however, to assume that oxygen levels above 10% will not be severely limiting to most mesic species and that lower levels can be tolerated, although they may be restricting, in many situations. Limiting oxygen levels are of particular concern when considering compacted soils for planting. As mentioned earlier, soil compaction itself limits gas exchange and may contribute to poor soil aeration. Raised soil grades, flooding or poor drainage can also restrict gas exchange. These limitations to aeration may be exacerbated by increased oxygen consumption by roots and microbes during the growing season (45).

Oxygen diffuses approximately 10,000 times more slowly through water than through air (28). Consequently, oxygen may be limiting when soil pores are filled with water. Water moves slowly through compacted soils due to insufficient macropores. Pores may thus remain water filled for longer periods than in a well aggregated soil. In a laboratory study, compaction to a bulk density of 1.54 g/cm^3 (compared to an uncompacted bulk density of 1.04 g/cm^3) reduced gas diffusion by only 38% when soil was dry. In wet soil, however, compaction reduced diffusion by 82% (10). The detrimental effect of water on oxygen levels is therefore intensified in compacted soils.

If drainage is adequate, it does not necessarily follow that compaction alone will produce limiting oxygen levels. In soils compacted to bulk densi-

ties of 1.75 - 1.88 g/cm^3, for example, researchers found numerous indications that poor aeration was not a factor in restricted root growth of cotton (38). Oxygen levels of 16.2 - 17.5% were measured one foot beneath an unpaved road whereas in an adjacent uncompacted area oxygen never fell below 20% (46). Thus compaction seems to have reduced oxygen levels, but not to a degree harmful to tree roots. On the other hand, oxygen levels as low as 4.0% were measured in the compacted soil under an asphalt road. Even here, however, oxygen levels returned to 20% during the dormant season. In a study by Boynton (4) of oxygen levels in an Upstate New York orchard with a dense silty clay loam soil, soil atmosphere oxygen content at a depth of 30 cm was consistently high throughout the year and never lower than 15.4%. At a depth of 90 cm, Boynton measured oxygen levels from 17.9% to less than 1%. Seasonal patterns were evident, the lowest readings being in March and April. These lower levels may be interpreted as a result of the higher water table in early spring, as oxygen levels were still most often 19 or 20% above the water table. Interestingly, when the water table dropped later in the summer, oxygen levels even in the densest subsoil at a depth of 180 cm ranged from 9.8-13.6%, not severely limiting for most plants. Oxygen apparently diffuses to a significant depth through dense soils when drainage is adequate. Consequently, although gas exchange may be slowed in compacted soils, this does not necessarily result in soil oxygen levels considered detrimental to root growth.

Other Factors

Compaction and drainage. Other factors like gas exchange, surface and subsurface drainage can also be limited by soil compaction. Water movement is difficult to characterize because it depends in part on soil matric potential which can vary greatly over short distances. This is especially true where the soil has been disturbed as is usually the case where trees are to be planted. Several drainage-related phenomena are influenced by compaction. Surface crusting can restrict water infiltration and thus increase runoff. Poor soil structure brought about by compaction slows water movement through the soil profile. These

two factors acting together are sometimes observed to allow water to collect in the bottom of a planting hole dug in compacted soil, thus flooding tree roots (44). Under dry soil conditions, the compacted soil could theoretically have the opposite effect as its higher proportion of micropores draws water out of the loosened soil in the planting hole.

Soil strength and soil moisture. Another facet of the relationship between compaction and water movement is the decrease in soil strength resulting from an increase in soil moisture (38). Resistance to penetration in a clay loam soil was found to decrease from 3.5 MPa to 2.1 MPa when volumetric soil moisture increased from approximately 27% to 40% (11). As discussed earlier, 2.3 MPa can be considered a critical soil strength above which woody plant roots will likely be greatly restricted. Soil moisture, via its effect on soil strength, must therefore affect root restriction in some soils.

Compaction and road salt. Compacted soils near roadside sugar maples were found to frequently have higher concentrations of sodium than nearby uncompacted areas. Slower water movement through compacted soils may have slowed the leaching of road salt and thus contributed to sugar maple decline (33) Clearly this is a complex situation, as sodium itself disperses soil aggregates (5), thus contributing to soil compaction.

Amelioration of Compaction

Many techniques have been used around landscape trees to ameliorate compacted soil or alleviate its associated stresses. Techniques can be roughly divided into three groups: remedial treatments around existing trees, treatments to reduce further compaction, and methods to alleviate soil compaction for an entire area before planting.

Remedial treatments. Many compaction remediation efforts have focused on improving soil aeration. Equipment designed to improve gas diffusion by injecting pressurized air into the ground to fracture the soil around existing trees has been available since the 1920s. Two of these devices, the Grow Gun and Terralift were shown to increase ODR readings at the soil fissures, but not

beyond. Neither method affected bulk density (34). Data on its effects on drainage and plant growth are not yet available. Enkadrain drainage mats placed vertically in a clay loam soil to act as aeration panels significantly elevated ODR up to 6 cm away from the mat one day after irrigating (24). After two days, however, this effect had dissipated. Although very short term, the aerating effect might allow roots to grow more rapidly while the soil strength is low.

Two years after remedial treatments intended to alleviate compaction stresses were installed around established Chinese wingnut trees, no differences in shoot growth were found (31). Treatments included vertical mulching (numerous augered holes filled with sand and milled fir bark); holes created by a high pressure water jet in a similar arrangement; and vertical, perforated, PVC pipe sump drains backfilled with gravel. Researchers concluded that in compacted sites, providing sufficient available water might be more beneficial to trees than attempting to improve aeration. It is not clear, however, how restrictive the existing compaction was to tree growth. Trees had been established for 10 years and showed reasonably good vigor. They therefore might not respond as measurably as more stressed trees. Radially arranged trenches filled with a friable soil extending outwards from the root ball zone, have been used in practice for some time, although no controlled evaluations were conducted until recently. Callery pears (*Pyrus calleryana* 'Redspire') planted into compacted clay loam with radiating sandy loam-filled trenches showed significantly greater shoot growth after two years than controls (11). Research with another type of trenching also indicates that such a method might provide favorable rooting space for plants. When trenches were dug in dense subsoil in rows of cotton and filled with less dense material such as vermiculite and loose soil, rooting depth of cotton planted on top of the trenched row increased as roots took full advantage of the looser soil below (16).

Preventative techniques. In areas where extensive foot or other traffic is expected, such as a city park or festival grounds, extremely compacted soil may be difficult to avoid. The use of soil amendments to reduce compaction on a heavily-

trafficked picnic area was examined by Patterson (30). Sintered fly-ash and expanded slate amendments resulted in lower bulk densities for as long as four years after being incorporated into the soil. Digested sewage sludge had little or no effect on bulk density. Sintered fly-ash and expanded slate are rigid, highly porous, inert materials, so it is to be expected that incorporating a high proportion (20 - 33%) of such low density materials would lower overall bulk density. Perhaps more interesting, is that the integrity of these materials appears to have been partially maintained after four years of heavy traffic. This seems to be especially the case for expanded slate, as bulk density was lower where this amendment was used compared to sintered fly-ash, even though its porosity was originally less (50% as compared to 70% for sintered fly-ash) The effects of these amendments on other soil properties and on plant growth have not been studied.

Soil preparation techniques. In contrast to the remedial and preventative compaction alleviation methods discussed above, considerable research has been conducted on the effects of subsoiling and tillage techniques, as these have long been of interest to agriculture. For woody plants, soil preparation in this sense is an option only where there are no existing trees or shrubs, or shallow utilities. For this reason, the long-term effects of deep tillage on soil strength and bulk density are critically important. Once trees are planted, the soil cannot be cultivated again.

Subsoiling compacted clay loam soil in Minnesota to a depth of 51 cm reduced penetration resistance by 50 - 80%. After settling during the winter, however, a reduction of only 20 - 55% was maintained (20). Furthermore, recompaction due to agricultural traffic the following spring increased penetration resistances 240 - 300%. Subsoiling to 60 cm in a sandy loam soil initially lowered soil strength and increased potato yields. After two years of conventional tillage, however, the original strength was almost restored and a yield effect was no longer shown (3). Consequently, it appears that the effect of deep tillage on soil compaction is short term, when considered in the context of the expected lifetime of a woody plant landscape. It may, however, alleviate soil compaction during the initial establishment of a new planting.

Amending the planting hole backfill with peat or other material is a traditional practice intended to relieve general transplanting stress. In general, most research indicates that little or no benefit is derived from this practice. However, the majority of this research has not focused on stressful site conditions, such as compacted soil. Consequently, a reexamination of the literature is of interest. In two Florida studies, amended backfill caused no benefits to container-grown plants. Unamended backfill produced greater root growth than peat-amended backfill in containerized pittosporum and juniper twelve months after transplanting into a sandy soil. A greater proportion of roots, however, were located in undisturbed field soil for the amended plants (19). Hummel found no differences in shoot and root growth between container-grown sweetgum trees planted into sandy soil with peat-amended backfill and those backfilled with native soil (18). Similar, although more variable results were found with container-grown azaleas, rhododendrons, hollies and junipers transplanted into a heavy clay soil (7). In container material, roots are already in a lightweight potting mix, high in organic matter. Therefore, an interface between the native soil and a mix with much higher organic content and a noticeably different texture is present whether backfill is amended or not. These results must therefore be interpreted carefully when considering bare root or balled and burlapped plants.

Corley analyzed the effects of a backfill amendment (33% pine bark by volume) and irrigation on bare root and balled and burlapped trees transplanted into compacted clay soil (7). For minimally irrigated bare root sugar maples, amended trees showed less growth after 2 years than unamended trees. After 3 years, this effect was no longer statistically significant. However, when both were kept well watered, amended trees had nearly twice the growth of unamended trees. Bare root and balled and burlapped dogwoods showed similar patterns, although the increase in growth was not as great. Balled and burlapped magnolias showed the lowest growth for amended trees with only minimal irrigation, and the highest for amended

with irrigation. Interestingly, while the bare root trees exhibited growth differences after both two and three years, the balled and burlapped trees exhibited differences among treatments only after the third year. One can speculate that before the third year, not enough roots had grown into the backfill area for it to have a significant effect on overall plant growth.

The interaction between irrigation and backfill amendment demonstrated in Corley's study may be related to the soil moisture stress shown by Costello in newly transplanted container-grown trees. In container-grown sweetgum trees transplanted into a well-drained loam soil, the container media were found to dry out faster than both the surrounding soil and the media of control trees transplanted into metal containers buried in the soil (8). This was attributed to drainage into the surrounding field soil after removal of the container at planting. As the surrounding soil dried, moisture transfer to the container media was not sufficient to meet evaporative demand. Container media were observed to be very dry even though it were in intimate contact with the moister field soil. The moisture stress created by the container media/soil interface described above is perhaps also a factor in the somewhat analogous situation created by using backfill amended with organic matter. Corley's research showed frequent irrigation to be critical to growth of bare root and balled and burlapped trees in amended backfill, offering circumstantial evidence in support of this analogy. The detrimental effects on plant growth tied to the use of amended backfill could therefore be attributed in some cases to low moisture availability in the planting hole. In sum, it appears that amending planting hole backfill has not been demonstrated to be either consistently beneficial or detrimental. However, when plants are well irrigated after transplanting, amendments seem to have a greater likelihood of improving growth, especially when surrounding soil conditions are poor.

Summary

Soil compaction is a serious problem for the landscaping industry that will continue to be with us for as long as modern construction methods are used and people pressures continue to increase on our landscapes. Soil with good structure is a valuable resource, worthy of protection during construction and other compaction-inducing activities. Where the damage has already been done, however, special efforts to improve plant establishment are often required. No universally successful technique is available. This is not surprising in that good soil and good soil structure are the result of countless years of naturally occurring physical and biological activity. We would not expect, then, that any quick fix could repair the damage done in soil compaction. Nonetheless, a full understanding of how compaction affects the growth of trees and shrubs and the relationship between soil moisture, aeration and compaction will be helpful to landscapers working with compacted site conditions. Many amelioration methods have focused on soil aeration. It now seems, however, that as long as drainage is adequate aeration is most likely not the primary restricting factor resulting from soil compaction. Techniques that physically reduce mechanical impedance and improve soil tilth are approaches that merit further exploration.

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Résumé. Les sols compactés sont un problème fréquemment rencontrés dans les aménagements paysagers et les sites de plantation en milieu urba in. De nombreuses méthodes pour améliorer les sites ainsi que des techniques de plantation ont été utilisées pour contrebalancer les effets dommageables de la compaction du sol sur la reprise des végétaux et leur croissance. Une recherche récente visant à examiner l'efficacité de ces techniques a débuté sur des résultats variables. Il est évident que la compaction restreint la croissance d'une plante ligneuse, mais la nature et les causes de cette limitation ne sont pas totalement comprises. Ceci est partiellement un résultat de la difficulté à séparer les effets causés par les changements dans l'«impédance» physique aux racines, aux échanges gazeu x du sol, à l'infiltration de l'eau et au drainage. Une revue de notre compréhension actuelle de la compaction du sol et de ses améliorations est présentée ici selon la perspective de végétaux ligneux utilisés en paysagement.

Zusammenfassung. Verdichteter Boden ist ein häufig auftretendes Problem der Grünanlagen in Städten und Gemeinden. Zahlreiche Standortverbesserungsmaßnahmen und Pflanztechniken wurden eingesetzt, um den schädigenden Effekten der Bodenverdichtung auf das Anwachsen und das weitere Wachstum entgegenzuwirken. Die jüngsten Forschungen mit dem Ziel, die Effektivität dieser Techniken zu untersuchen, haben mit unterschiedlichen Ergebnissen begonnen. Es ist erwiesen, daß Verdichtung das Wachstum von mehrjährigen Pflanzen unterdrückt, aber die Natur und die Gründe fur diese Unterdrückung sind nicht vollständig verstanden. Das ist teilweise ein Ergebnis der Schwierigkeit, die Auswirkungen, verursacht durch Wechsel in der physikalischen Behinderung der Wurzeln, Bodenluftaustausch, Wasserzufuhr und Durchlässigkeit, voneinander zu trennen. Ein Rückblick auf unser gegenwärtiges Verständnis von Bodenverdichtung und seinen Verbesserungen ist hier dargestellt aus der Perspektive des Garten-/Landschaftsbaus.