AREA Forum

METHODS TO EVALUATE SOIL COMPACTION

In the first AREA Forum (May 1999), Sharon Lilly, Susan Wiegrefe, Bonnie Appleton, and Roger Kjelgren discussed how to communicate scientific complex concepts to arborists and educators. In the second and third forums, arborists and researchers from around the world answered the questions, What are the principal problems that trees face in your city? and How do you think these problems could be solved? C.Y. Jim from Hong Kong, Thomas Randrup from Denmark, María du Carmo Sanchotene from Brazil, Alicia Chacalo from Mexico, Stephan Pauleit and Friedrich Duhme from Germany, and Daniele Zanzi from Italy participated in those forums, published in September and November 1999.

This time, we asked 5 researchers to compare their experiences with different methods for evaluating soil compaction in an urban environment. That topic will be continued in March 2000. If you would like to participate, please send your response to the *Journal* Editor (see inside cover) or to me at: ach@hp9000a1.uam.mx. We also invite additional commentary to be submitted for inclusion in future issues.

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In my research, I have used both bulk density and penetrometer resistance to quantify soil compaction. Both of these methods are useful diagnostic tools for researchers and arborists. We must have a full understanding of the limitations of each method, however, when comparing data from one experiment to another.

Bulk density is the ratio of the mass of an oven-dried sample of soil over its volume. Because the samples taken must be disturbed as little as possible, a slide-hammer core sampler is usually used to extract soil from the site in metal sleeves, which are then shaved down to a precise volume. Bulk density measurements are easy to make and require little equipment (an oven and a sampler). Provided enough samples are taken, bulk density data are very consistent and repeatable. Disadvantages are that considerable digging is needed to take samples lower down in the soil profile. This is laborious and, in an experiment, the site disturbance can interfere with the compaction effects you are trying to study. Bulk density data are excellent for comparing the degree of compaction of soil from different sites and experiments, with one caveat. We must always take into account the soil texture and any special soil properties (such as the presence of porous volcanic soils). The natural porosity of uncompacted soil varies considerably with soil texture. In general, a soil high in clay content tends to have a lower bulk density than one high in sand content. Some tables have been published attempting to create guidelines for determining compaction severity for various soils based on their bulk densities.

This disadvantage is why many people prefer to use penetrometer resistance as a measure of soil compaction. The penetrometer is easy to use, and many measurements can be taken quickly and without disturbing the soil greatly. A metal rod, usually with a cone tip, is pushed into the soil and the force required to push it in is measured. The primary disadvantage is that, for research purposes, this information is not useful unless soil moisture information is gathered simultaneously. The penetrometer will push through wet clay soil as if it were butter. The same soil could be very difficult to penetrate when dry. For assessing soil compaction on a proposed planting site, however, I believe that if an arborist became experienced in using the penetrometer, he or she would be able to make reliable judgments about whether the soil was compacted without collecting soil water content data. Also, the penetrometer is ideal for detecting hardpans.

Time domain reflectometry (TDR) has made collecting soil moisture data much easier than in the past—and the soil need not be disturbed. Otherwise, samples must be collected at each depth you wish to study and soil moisture determined. This is time consuming and negates the advantage of low soil disturbance. However, these data provide an excellent picture of the soil strength at various moisture levels for a given soil. Soil strength generally decreases as water content increases, but the degree to which this occurs varies considerably. Much has been made of the different styles of penetrometers and whether they truly imitate the way a root forces itself through the soil. However, I believe that for our purposes in arboriculture research and fieldwork, these considerations are not terribly important. When full moisture data are collected and the data graphed (soil strength versus soil water content), penetrometer readings can be used to compare compaction levels between sites. These data cannot be as easily communicated, however, as bulk density data.

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In scientific research, there are a number of methods to evaluate soil compaction. The best known is bulk density, which is the ratio of mass to the bulk or macroscopic volume of soil particles plus pore space in a sample.

Bulk density can be determined by the core method, that is, a cylindrical metal sampler is pressed into the soil and carefully removed. Samples are then oven-dried and the bulk density is calculated. The core method is often unsatisfactory if more than an occasional stone is present in the soil. The method also requires many replicates to be satisfactory.

Another method is excavation. A quantity of soil is excavated, dried, and weighed, and the volume of excavation is determined with a known volume of sand or by filling the hole with water after sealing the walls.

Road engineers often use radiation methods. The main disadvantage of radiation, for our purposes, is that it often measures a mean of, for example, 30 cm and if there are thin, compacted horizons you won't notice these, but they may be very important in restricting water and air transports.

Another useful diagnostic tool is a penetrometer. Any device forced into the soil to measure its resistance to vertical penetration may be called a penetrometer. There are some recording penetrometers on the market, but what do they actually measure? The figure you get depends on the actual water content of the soil and therefore it is difficult to obtain absolute values of what is good or bad for root growth. On the other hand, a penetrometer is good for comparing soil conditions within a certain area with the same soil texture.

A steel rod with an attached cone can, with a little experience, give you some information about the different horizons in the soil and is a good tool for assessing where to do further investigations.

A penetrograph is a penetrometer with a recording chart that immediately provides a curve of the resistance with depth. An electronic version is the penetrologger.

Which of these are practical for an arborist to use? A steel rod, a spade, and a knife will give you much information. If you still are unsure about how good the soil is for plant growth (i.e., how good the pore system is), you should do infiltration tests.

The pore system in the soil contains predominantly water and air. Too much water in the soil means a shortage of oxygen. Although many plants can tolerate a shortage of oxygen, many others are sensitive to a shortage. A high groundwater level can be the reason for oxygen deficiency. Other causes include compacted soil, or more rain than the pore system in the soil can transport.

When the soil is compacted or there are compact layers in soil, precipitation might fill the pore system completely. This problem occurs mainly when the soil contains very small particles (as with clay soils), or when highly decomposed organic material is present.

When a soil is investigated, from the soil physical side, the saturated hydraulic conductivity is often measured. In other words, how quickly water runs through soil when the soil is wet. This value is a measure of how much rain (mm/hour, in./hour) the soil can transport when it is wet. The expected rain intensity during a wet and cool season (when the evapotranspiration is low) in an area is the smallest value the hydraulic conductivity can have, without causing problems for plants. The saturated hydraulic conductivity is measured in soil cores in the lab by different methods.

Field measurements have one big disadvantage: You never know which way the water is transported through the soil. The water can be horizontally transported on a more compacted layer. The field methods can, however, give a good picture—as long as you are aware of this weakness, make several measurements at different depths in the soil, and have first investigated the soil by digging, penetrometer, or other tool.

Many types of field measurements are used. Further information can be found in Methods of Soil Analysis (Black 1965). The double-tube method, which in the past had been used primarily in the lab, is now being used in the field. Special equipment is required. Another tool is a single- or double-cylinder infiltrometer. The cylinders have a diameter of 12 to 48 in. and are 10 to 14 in. high. They are driven into the soil layer you want to examine. The rings are filled with water, and the soil should be saturated with water before starting the measurements. Measurements can start when the water table is sinking with an even speed. The method requires large quantities of water.

There are also different types of auger-hole and well-pump methods used below and above the water table. A hole is made and measurements are taken of how quickly water comes in (pumping out water from the hole) or goes out (fills the hole with water) of the hole.

An easy, but often inadequate, method can be used in small areas, as long as the soil is also investigated by other methods. Dig a hole and pour a bucket of water in the hole, then measure the amount of time it takes the water to disappear.

If the area carries vegetation, the species and the condition of vegetation can provide a good idea the level of compaction over a large area. Taking a good look at the area during a wet and cool period (when the evapotranspiration is very low) can also give a good idea of the condition of the soil (flooding). As long as the soil is not in too bad condition, these problems can be avoided by choosing plants that tolerate oxygen deficiency in wet periods, or by using raised planting areas. The higher areas are seldom wetter than the lower areas.

Literature Cited

Black, C.A. (Ed.). 1965 Methods of Soil Analysis. American Society of Agronomy, Madison, WI.

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Important soil qualities for tree growth in cities are the water retention curve and hydraulic conductivity (determining the water regime), the coefficient of oxygen diffusion (determining the oxygen regime), penetration resistance that growing roots encounter, and the bearing capacity protecting the relatively loose soil from compaction by surface loads. These qualities are determined by the intrinsic soil properties (size and shape of the mineral grains, organic matter) and by soil structure (particle arrangement and bonds). Prevailing structure of tree soils in cities is determined by the structure that existed immediately after growing site establishment and by structural changes as time elapsed after establishment. This means that the prevailing structure may be influenced by compactive actions during the establishment of the growing site and by compactive events thereafter.

It is difficult to relate particle arrangement and bonds to tree growth. It is more convenient to relate the growth of trees to the above-mentioned soil qualities. Such relations are subject in mechanistic, deterministic models of growth, water flow, gas transport, pavement sinkage, etc. This means that soil compaction should preferably be measured in terms of water retention and hydraulic conductivity, coefficient of oxygen diffusion, cone penetration resistance, and bearing capacity. Because these quantities depend on the soil water content, they should be measured at a range of water contents or at standardized water contents.

Soil compaction is intensively studied for agricultural crops. The results of these studies are well documented (Koolen and Kuipers 1983; Larson et al. 1989; Soane and Ouwerkerk 1994).

Major differences exist, however, between growing sites for agricultural crops and for city trees. Research should primarily concentrate on these differences. In the city, it is very important to distinguish between rootable and unrootable soil volumes. The tree soil may be loaded through pavement by traffic, or protected by a cellar-like construction that carries the traffic. Tree soil may be natural, amended, or manufactured. The compaction action at establishment may be highly controlled and checked; for instance, it may be done with a prescribed type of vibrating tamper at prescribed thicknesses of soil layers, repeated a prescribed times, and performed within a prescribed range of soil water content. It is important to have a laboratory procedure that compacts small amounts of prepared soil in such a way that the resulting compaction is similar to that which occurs in practice. Often, the oxygen regime of tree soil is critical. So, measuring coefficient of oxygen diffusion and the oxygen consumption of tree soil are relatively important. It is very convenient to measure soil qualities on small soil samples in the laboratory. This needs a micro-penetrometer and a value to translate micro-penetrometer readings into values that apply to a full-size penetrometer. Trees and tree-growing periods are relatively large. Looking at the condition of city trees, which is often unsatisfactory, it may be concluded that there is a great need to develop special growth models for city trees. A further need is the ability to predict the settlement of the relatively loose tree soil due to repeated loading by relatively light traffic.

In practice in the Netherlands, outside the laboratory, a penetrometer is used in two situations: to explain patterns of root growth of trees, mostly in pavements, and to check the compaction level of Amsterdam Tree Soil during installment.

We have found the penetrometer an excellent aid in explaining tree root growth in inner cities, especially when compaction is high. We use the penetrograph, which records the results on a cart in the form of a graph of penetration resistance against depth. We find it gives a lot of information and takes only a little time. Our method is as follows: We dig a pit in the soil and take an penetrograph reading. If the penetrograph gives penetration resistance over 3 MPa and seems to coincide with the rooting pattern, we decide that a high compaction level is the reason for the rooting pattern (and in a great number of cases, bad tree growth). We then advise that something should be done about it. If not, we look for other causes of bad tree growth, such as coloration of the soil (excess water or lack of oxygen) or gas leaks. If we cannot find an explanation, we begin to take samples (pH, nutrition, etc.).

Of course, we have mostly sandy and loamy soils in the Netherlands, so taking penetrometer readings is possible in many cases. Still, apart from being easy, there are other reasons to be partial to penetrometer readings, especially in the higher compaction regions. If a soil is highly compacted, the only really reliable method of establishing the soil density is the balloon method, as used by civil engineers. This method, however, can be used only in soils that do not contain sharp particles. Where sharp particles exist, you can either use rings to take undisturbed soil samples or use the sand-cone method. Either method gives an error: the ring method because of particles that will not fit into the ring, which give a hole in the sample where no hole was *in situ*; and the sand-cone method by sand disappearing in large pores, which are in a lot of cases present when coarse particles are present in the soil. Besides, if you want to be able to say that a soil is limiting to root growth, there should be data on the upper-density boundary of the soil in which trees still can grow. This boundary will differ for each individual soil and must be determined for each soil separately.

For Amsterdam Tree Soil, the relationships between soil density, water content, and penetration resistance are studied quite extensively. Because of that (and because the soil is sandy), it is possible to use a penetrometer to control the density of the soil during filling in and compacting the soil. This is especially the case, because this is done at specified water contents of the soil. The ease of use of a penetrometer makes controlling the compaction action highly accurate: You can tell when to stop.

Of course, when you find low penetrometer readings in unknown soils, you have to be aware of the influence of water. The soil can still be highly compacted, but due to a high water content, flexible. There is no way to avoid this error but through proper training.

Literature Cited

Koolen, A.J., and H. Kuipers. 1983. Agricultural Soil Mechanics. Advanced Series in Agricultural Sciences, 13. Springer Verlag, Heidelberg, Germany. 241 pp.

Larson, W.E., G.R. Blake, R.R. Allmaras, W.B. Voorhees, and S.C. Gupta (Eds.). 1989. Mechanics and Related Processes in Structured Agricultural Soils. Proceedings of the 2nd Workshop, St. Paul, MN, 1988. NATO ASI Series E: Applied Sciences, Vol. 172, Kluwer, Dordrecht, the Netherlands. 273 pp.

Soane, B.D., and C. van Ouwerkerk (Eds.). 1994. Soil Compaction in Crop Production. Developments in Agricultural Engineering 11. Elsevier, Amsterdam, the Netherlands. 662 pp.

BOOK REVIEW

Physiology of Woody Plants (2nd ed.). 1997. By Theodore T. Kozlowski and Stephen G. Pallardy. 411 pp., biblio., index, afp. Published by Academic Press. ISBN 0-12-424162-X, US$69.95.

This welcome second edition updates and amplifies the well-known 1979 work of the same title by Paul J. Kramer and Kozlowski. The field has changed dramatically, and the authors have included a wealth of new information. Perhaps half or more of the extensive reference list is new, and many cited works were published within the last 5 years. This is a reference work as well as a text, serving its broad intended audience, including students, growers, and researchers, with general information and an entry to the primary literature.

The initial, well-referenced chapters on plant structure, vegetative growth, and reproductive growth provide more detail than a general botany text. Chapters highlight such topics as photosynthesis and water balance, common to any plant physiology text, but the focus is on whole-plant physiology of woody plants, with cellular-level phenomena receiving only superficial treatment. The organization is occasionally puzzling: Enzymes and energetics are introduced after the chapter on photosynthesis. Conflicting views on controversial topics, such as recent challenges to the tension-cohesion model for the ascent of sap, are presented and supported with references.

Upper-division undergraduates through professionals.

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