Soil Compaction Impacts On Tree Roots

by Dr. Kim D. Coder, University of Georgia July 2000

Compaction impacts trees in many ways. Generally, compaction associated physiological dysfunctions cause systemic damage and decline, as well as failures in dealing with additional environmental changes. Physical / mechanical constraints negatively modify responses in the tree resulting in inefficient use of essential resources. The symptoms we see in trees under compacted soil conditions have causes stemming from disruptions of the internal sense, communication, and response process.

Biological Disruptions

Compaction disrupts respiration processes which power every function of the tree. Growth regulators are destroyed prematurely or allowed to buildup, causing wild changes in tissue reactions. Carbon allocation patterns, following highly modified growth regulation patterns, change food production, storage, use, and transport processes. Defensive capabilities with degraded sensor functions, associated growth regulator communications, and ineffective food use, is slow to react and incomplete in response. With compaction, short-term fluctuations in resource quality and quantity must be effectively dealt with and resulting chronic stress must be tolerated.

The presence of toxic materials can be highly disruptive to soil health. As oxygen concentrations decline, more reduced compounds (only partially oxidized) are generated by the tree roots and associated soil organisms. These reduced compound can buildup and damage organisms and move the soil toward anaerobic conditions. In normal soils, these materials (if produced at all) are quickly oxidized or removed from near tree roots. In compacted soil, normally produced materials, materials produced under low oxygen conditions, and anaerobically produced compounds are not oxidized nor removed from where they are produced. The longer the residence time of some of these materials, the more damage.

Structural Disruptions

The structure of the tree can also be directly and indirectly impacted by compacted soils. Root decline and death can lead to catastrophic structural failures. Tissue death and subsequent compartmentalization processes can compound mechanical faults. Growth regulation and carbon allocation changes can modify stem and root collar taper and reaction wood development. Whole tree stress can result in tissue shedding internally to heartwood and externally. Top and root dieback as well as branch drop can be the result. Reduced rooting volume mechanically destabilizes the whole tree.

UNIVERSITY OF GEORGIA WARNELL SCHOOL OF FOREST RESOURCES EXTENSION PUBLICATION FOR00-8
WEB Site = WWW.FORESTRY.UGA.EDU/EFR

Compaction Effects

Major soil compaction effects on trees are defined below:

Reduced elongation growth – As compaction increases, roots are physically prevented from elongating into the soil by lack of O2, by decreasing pore size, and by increased soil strength. As roots are put under greater than 1.2 MPa of pressure, elongation slows and stops. Figure 1.

Reduced radial growth – Trees begin to generate thick and short roots with many more lateral roots as surrounding soil pressure exceeds 0.5 MPa. O2 shortages and soil strength are major limitations.

Essential element collection and control problems – With less colonizable soil volume, there is less physical space to collect resources from and less resources within that space. With declining respiration processes, energy requiring steps in active element uptake (i.e. N, P, S) fail. Part of the difficulty in collecting essential resources is a buildup of toxics which pollute any existing essential resource supply.

Shallow rooting – As roots survive in a steadily diminishing aerobic layer, and as the anaerobic layer expands toward the surface, the physical space available for living roots declines. The consequences of having smaller volumes of colonizable space at the surface of the soil means roots and their resources are subject to much greater fluctuation in water, heat loading, and mechanical damage. Drought and heat stress can quickly damage roots in this small layer of oxygenated soil.

Constrained size, reach, and extent of root systems – Compaction limits the depth and reach of tree root systems leading to greater probability of windthrow and accentuating any structural problems near the stem base / root collar area. Limiting the reach of the root system also prevents effective reactions to changes in mechanical loads on the tree and concentrates stress and strain in smaller areas.

Stunted whole tree form – As resources are limited by soil compaction and more effort is required to seek and colonize resource volumes, trees are stunted. The disruption of growth regulation produces stunting as auxin / cytokinin ratios shift resource allocations and use. In addition, carbohydrate and protein synthesis rates enter decline cycles interfering with nitrogen and phosphorous uptake, which in-turn disrupts carbohydrate and protein synthesis. The result is a tree with a small living mass and with limited ability to take advantage of any short-term changes in resource availability.

Seedling establishment and survival problems – Micro-site variability in compaction levels and a limited resource base constrain young and newly planted trees. Less of a bulk density increase and crusting effect are needed for failure of new trees compared with older, established trees.

Root crushing and shearing-off – The mechanical forces generated in compacting a soil can crush roots, especially roots less than 2 mm in diameter. Larger root can be abraded and damaged. Rutting can shear-off roots as soil is pushed to new locations. The amount of crushing is dependent on root size and depth, weight of the compacting device, soil organic material, and depth to the saturated layer (for rutting). Figure 2.

Fewer symbionts / codependents – Soil compaction puts selective pressure against aerobes and favors low O2 requiring organisms, like Pythium and Phytophthora root rots, or anaerobes. Because of the destruction of the detritus energy web coupled with successional changes, recovery of soils to pre-compaction conditions may not be possible. Management must move forward to new solutions for resource availability and deal with new patterns of pest management since returning to the soil microbiology and rhizosphere of pre-compaction is impossible.

Renovation of Sites

Principles -- A summary of this discussion of soil compaction lies with those general principles and renovation techniques managers must use to reclaim a part of the ecological integrity of the site, as well as soil and tree health. General soil compaction renovation principles are listed below in a bullet format:

– Soil compaction should be considered permanent. Studies demonstrate that after one-half century, compaction still afflicts soils under natural forest conditions. Recovery times for significant compaction is at least two human generations. Soils do not "come back" from compaction.

– Every soil used by humankind has a representative compacted layer, zone, area, or crust. Changing management may not change the current compacted zone but may well add an additional compacted zone in a new position.

– Management activities should concentrate on moving forward to increased aeration space and reduced soil strength as best you can, rather than trying to recover past ecological history.

– Measure bulk density, penetration force, O2 diffusion rates, and tree available water. These are the best proxy measures we have to understand soil compaction and its impacts on trees. More careful and direct measures of soil compaction constraints on tree growth are expensive and difficult to make.

– Alleviation of soil compaction is part of a good soil health management plan.

– Use extreme caution in management of water over and in compacted soils. Compaction provides little margin for error for drainage, aeration, infiltration, and water holding capacity of tree available water. (Wet soil / dry tree problems).

– Seek the assistance of a tree and soil specialist to avoid tree-illiteracy problems on compacted soils.

Techniques – Once the general principles of working with compacted soils are digested, the next requirement is to identify some techniques for renovating compacted soils. These recommendations are generic across many situations and soil types. General techniques are listed below in a bullet format:

– Restrict site access to the soil surface as soon as possible with fences and fines (legal penalties). Try to be the first one on the site and setup anti-compaction protection.

– Defend the ecological "foot print" of the tree rooting area. Select working conditions (dry, dormant season, surface mulch, etc) that minimizes compaction.

– Restrict where possible vibrational compaction.

– Carefully design tree growth areas using "biology-first" design processes rather than the common (and damaging) "aesthetics-first" design processes.

– Try to soften and distribute compaction forces with temporary heavy mulch, plywood driving pads, and soil moisture content awareness planning.

-- Restart or improve the detritus energy web in the soil including addition of organic matter and living organisms, as well as trying to change soil physical properties by increasing aeration pore space.

Conclusions

Soil compaction is a hidden stressor which steals health and sustainability from soil and tree systems. Causes of compaction are legion and solutions limited. Without creative actions regarding the greening of inter-infrastructural spaces in our communities, we will spend most of our budgets and careers treating symptoms and replacing trees. Understanding the hideous scourge of soil compaction is essential to better, corrective management.

For more information on this subject review papers listed in the following reference: *Coder, Kim D. 2000.* ***Trees and Soil Compaction: A Selected Bibliography.*** *University of Georgia School of Forest Resources Extension Publication FOR00-1. 2pp. (Download at WEB site www.forestry.uga.edu/efr under "tree health care.")*

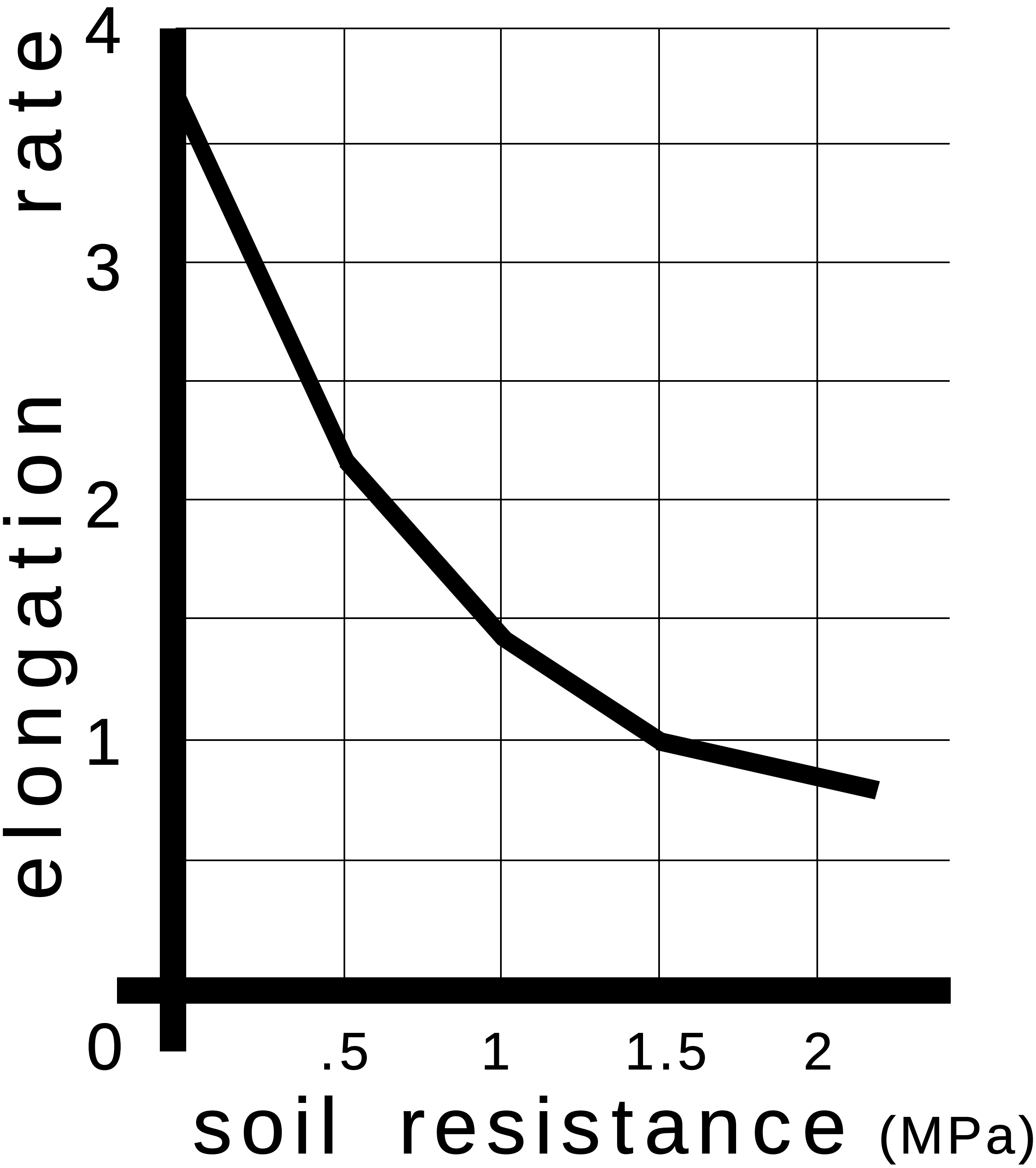

Figure 1: Soil penetration resistance and root elongation rate. (after Rendig & Taylor 1989)

(1 MPa =100 kPa ▪ 1 bar)

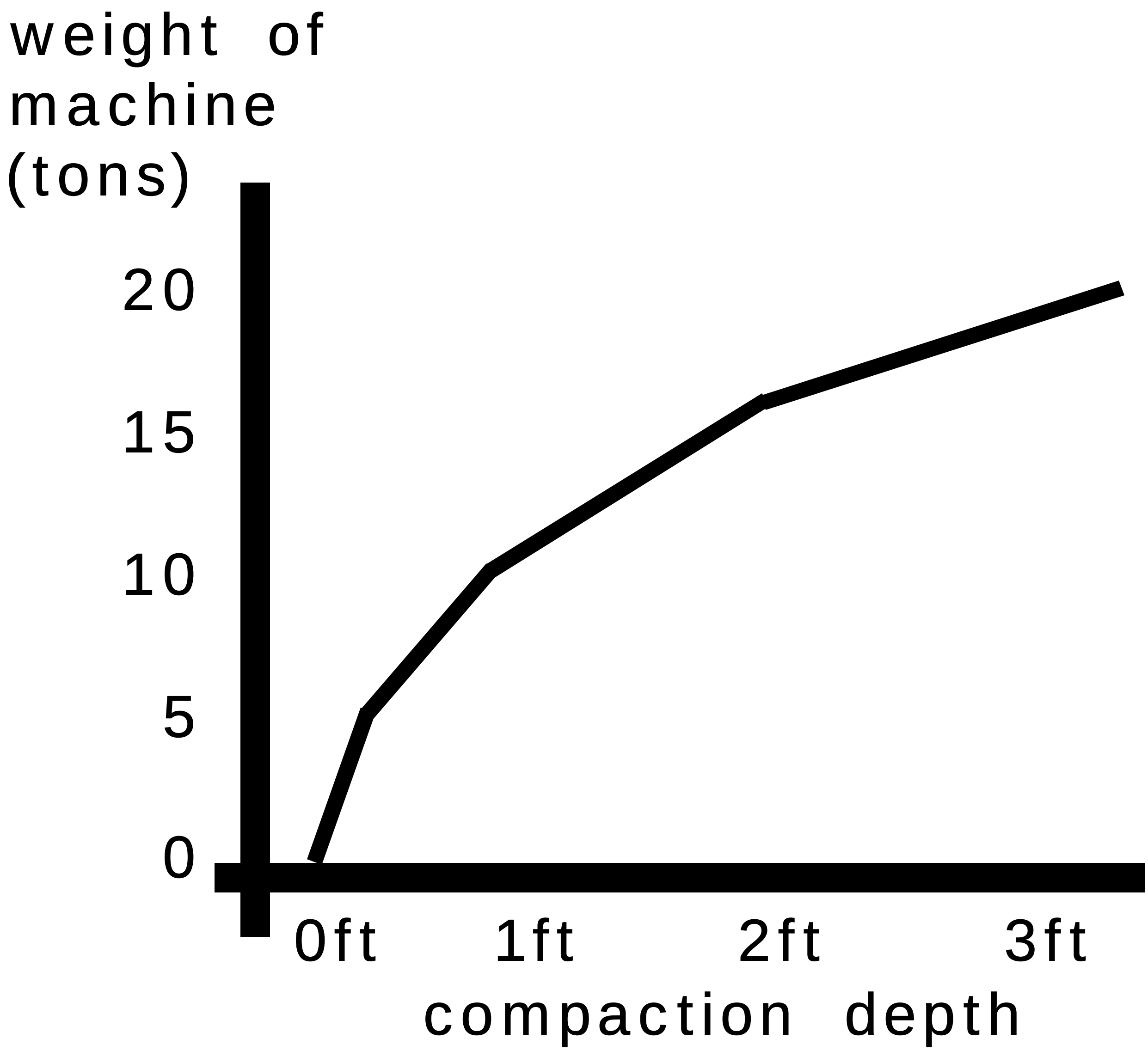

Figure 2: Depth of soil compaction under machines of various weights. (after Randrup 1999)