Soil Damage From Compaction

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Having reviewed the primary means by which soils become compacted, the results of compaction can be estimated for tree and soil health.

<u>Destruction of soil aggregates and large pore spaces</u> – The pore spaces from cracks, interface surfaces, biotic excavations, organic particle decomposition, and normal soil genesis processes help oxygenate the soil matrix. By definition, compaction results in the destruction of soil aggregates and aeration pore spaces. Pore spaces filled with O2 and interconnected with other aeration spaces exchanging gases with the atmosphere are critical to a healthy soil and tree root system. The destruction of aeration spaces surrounding soil aggregates can be unrecoverable.

<u>Resorting / redistribution of particles</u> – (Change in particle distribution) Particles of soils are redistributed into new locations, many of which are open pore spaces in the soil matrix. Through processes of packing, erosion, and cultivation many fine particles can fill-in the spaces surrounding other particles, as well as the spaces between structural aggregates. Some soil types can be compacted more easily through this process than others. Mid-textured soils with a mix of particle sizes can be strongly compacted due to particle size availability to fill any size of pore space.

<u>Total pore space changes</u> – (Change in pore space distribution) Compaction initiates a redistribution of pore sizes within the soil matrix. Large pores are destroyed and small pore are generated. The total pore space of the compacting soil initially increases as more capillary pores are created as aeration pores are lost. With increasing compaction, soil strength increases and pore space declines. Figure 1.

<u>Aeration pore space destruction</u> – The crushing collapse of aeration pores facilitates the upward movement of the anaerobic layer. There are always anaerobic and aerobic micro-sites in and around soils aggregates within the surface layers of soil. The dynamic proportions of each type of micro-site changes with each rainfall event and each day of transpiration. Compaction shifts proportional dominance in the soil to anaerobic sites. With further compaction, aerobic sites are concentrated closer and closer to the surface until little available rooting volume remains. Table 1 lists root-limiting aeration pore space percentages in soils of various textures. Air pore space less than 15% is severely limiting.

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Increased mechanical impedance – Compaction brings soil particles into closer contact with each other (less moisture and/or greater bulk density). Closer contact increases surface friction and soil strength. As soil strength increases and pore sizes decrease, the ability of roots to grow and colonize soil spaces declines rapidly. With compaction, soil strength reaches a level where roots can not exert enough force to push into pore spaces. Pore space average diameters significantly smaller than average root diameters are not utilized by tree roots. Figure 2. Table 2 lists root-limiting bulk densities by soil texture. The texture and bulk density must be known to estimate compaction impacts.

Connectivity of aeration pores decreased – The aeration pathway (lifeline) from the atmosphere to the root surface through all the interconnected aeration pores declines quickly with compaction. As the tortuosity of the oxygen supply path increases, the closer to the surface the anaerobic layer moves. As pore sizes become smaller with compaction, more of the pore space is filled with water. Water-filled pores diffuse O2 at rates 7,000 to 10,000 times slower than air-filled pores. With all the other aerobes and roots in the soil competing for the same oxygen, oxygen limitations become severe. Figure 3.

Poor aeration – Compaction constrains O2 movement in the soil and shifts soil toward anaerobic conditions. Less O2 diffusion into the soil leads to a chemically reducing soil environment (both the soil solution and soil atmosphere). Under these conditions, toxins and unusable essential element forms are generated. In addition, organic matter is not mineralized or decomposed.

A soil anaerobic respiration sequence is initiated among bacteria starting with nitrogen and moving through manganese, iron, and sulfur, ending with carbon (fermentation of roots). Tree roots are aerobes as are root symbionts and co-dependent species of soil organisms. Less oxygen prevents growth, defense, and survival in aerobes. Roots use available food 20 times more inefficiently under near anaerobic conditions. Less oxygen also allows common pathogenic fungi which have oxygen demands must less than tree roots to thrive. As O2 concentration falls below 5% in the soil atmosphere, severe root growth problems occur. Figure 4. Figure 5. Figure 6.

Poor gas exchange with atmosphere – Compaction prevent gas exchange with the atmosphere. Compaction prevent O2 from moving to root surfaces, but also prevents CO2 and toxics (both evolved and resident) from being removed from around the roots and vented to the atmosphere. Poor gas exchange allows the anaerobic layer to move closer to the surface and reduce rooting volume. As CO2 comprises more than 5% of the soil atmosphere, problems of aeration become compounded. As CO2 climbs above 15% in soils, root growth dysfunctions accelerate. Figure 7.

Less tree available water / Less water holding capacity – One of the most ignored result of compaction is it effects on soil water availability. Soil compaction reduces the tree available water held in the large capillary pores and increases the volume of small capillary pores which hold water unavailable to trees. With the decreasing number of large capillary pores and increasing number of small capillary pores, the total water holding capacity of the soil declines. Irrigation scheduling and monitoring becomes critical around trees in compacted soils. Figure 8. Figure 9. Figure 10. Figure 11.

Decreased infiltration rates / Increased surface erosion – Compaction leads to smaller pore spaces and slower infiltration rates. With increasing residency time at the soil surface, water can horizontally move across the surface of the soil initiating erosion. Over the top of compacted soil, water can reach faster velocities (more erosion potential) than in areas where it infiltrates easily.

Poor internal drainage – Compaction prevents effective drainage of soils. Poor internal drainage limits tree available water, prevents O2 movement, and increases production and residence time of CO2 and toxics.

Increased heat conductance – Compaction changes the energy and water balance near the surface of the soil. With more particle to particle contact, heat transfer is greater into the soil. Results include burning-out of organic matter quicker, acceleration of evaporative and transpirational water loss, and increased respiration of roots and soil organisms. As temperature increases, respiration responds along a doubling sequence path – for every 18°F (10°C) increase in temperature, respiration doubles.

Conclusions

The soil has many interacting features which provide a growing environment for tree roots. Modification of just a few (or one) can lead to severe survival and growth problems. Small soil changes can lead to large consequences for tree and soil health.

Table 1. Root growth limiting air-pore space values by soil texture.

soil texture	root-limiting % pores normally filled with air
sand	24%
fine sand	21
sandy loam	19
fine sandy loam	15
loam	14
silt loam	17
clay loam	11
clay	13

Table 2. Root growth limiting bulk density values by soil texture.

soil texture	root-limiting bulk density (g/cc)
sand	1.8 g/cc
fine sand	1.75
sandy loam	1.7
fine sandy loam	1.65
loam	1.55
silt loam	1.45
clay loam	1.5
clay	1.4

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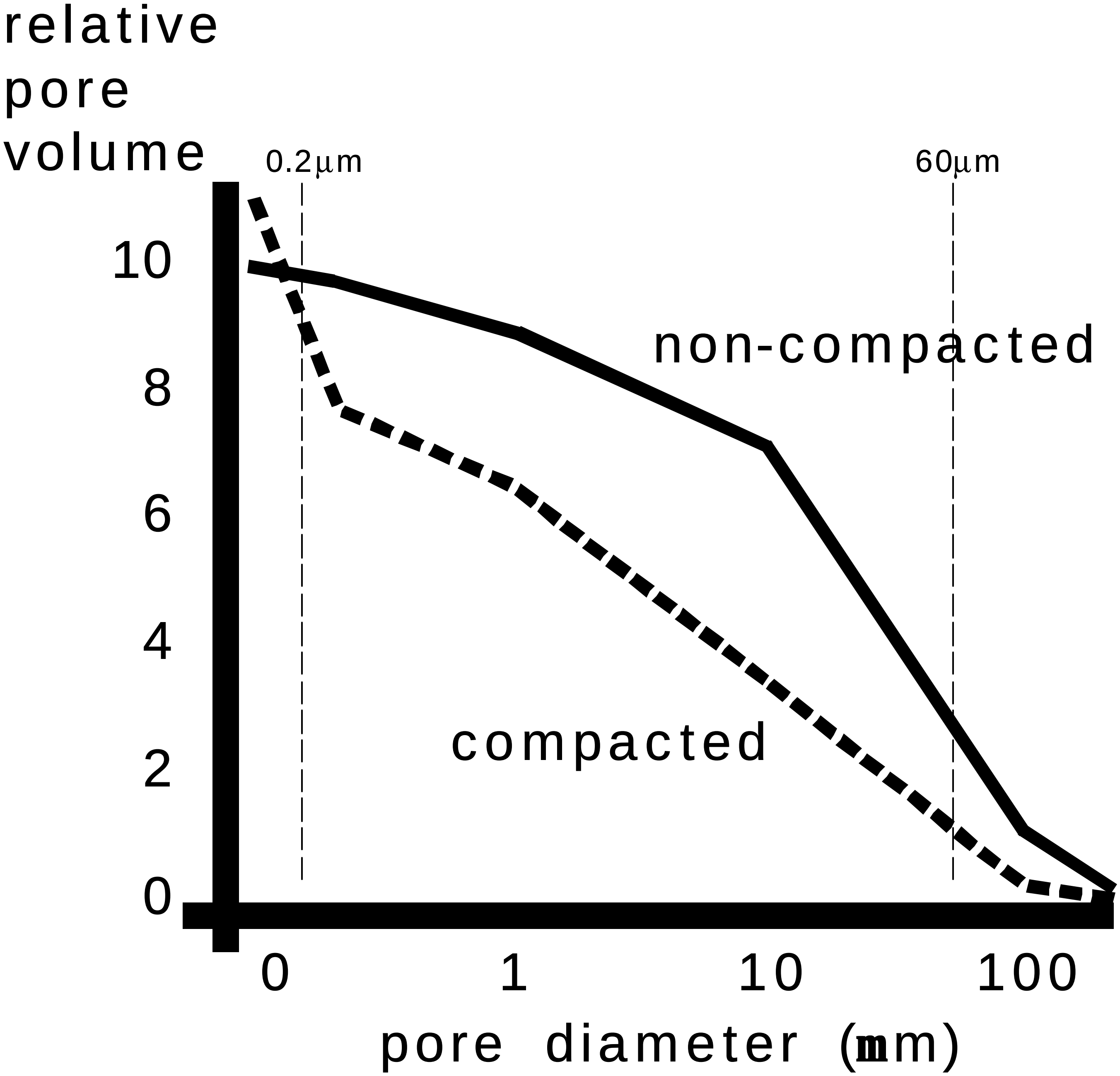

Figure 1: Soil pore diameters and relative volumes under non-compacted (1.4 g/cc) and compacted (1.8 g/cc) conditions.
(after Jim 1999)

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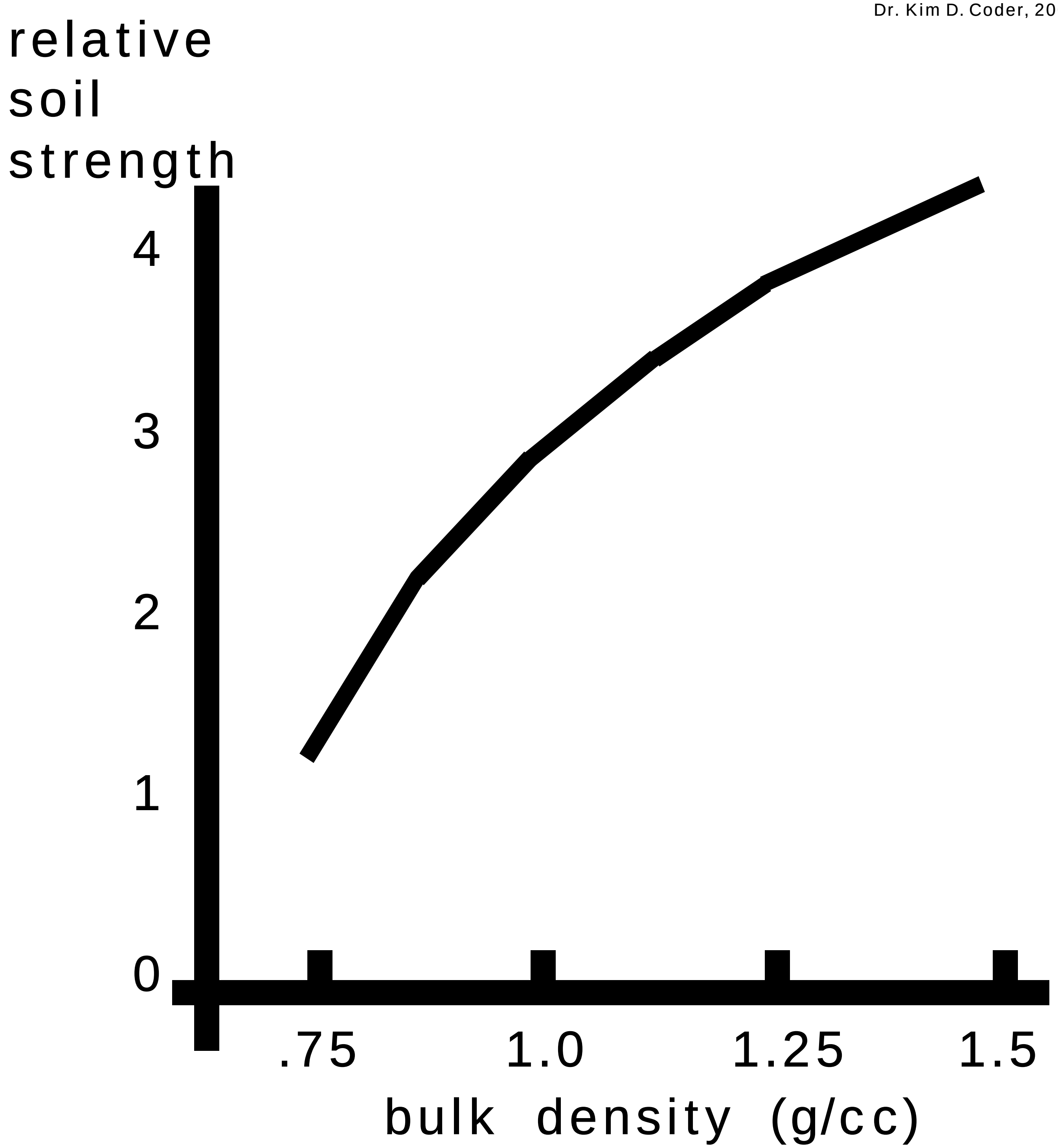

Figure 2: Relative soil strength with increasing bulk density values.
(after Craul 1994)

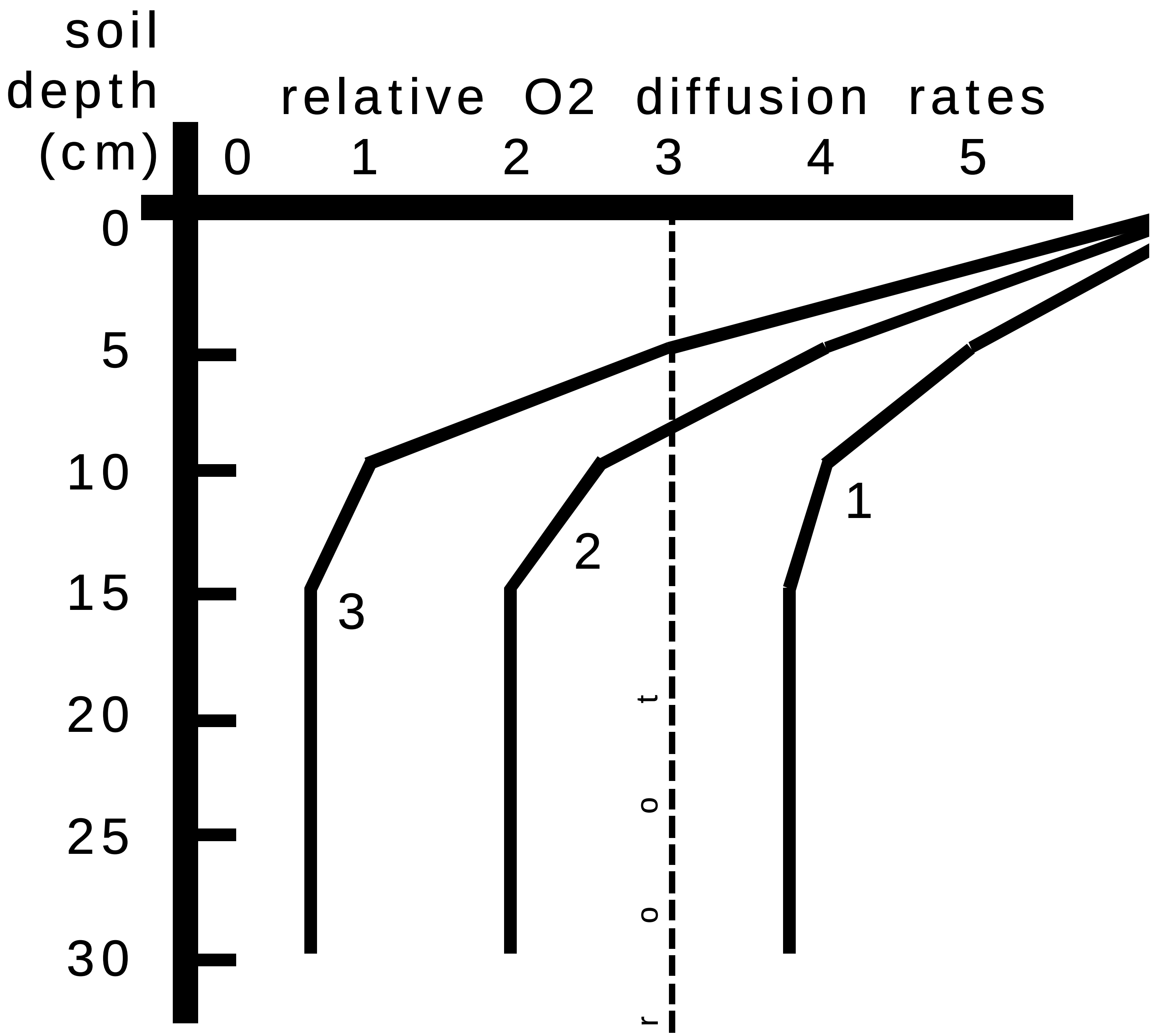

Figure 3: Relative oxygen (O2) diffusion rates with increasing soil compaction. (after Kelsey 1994)

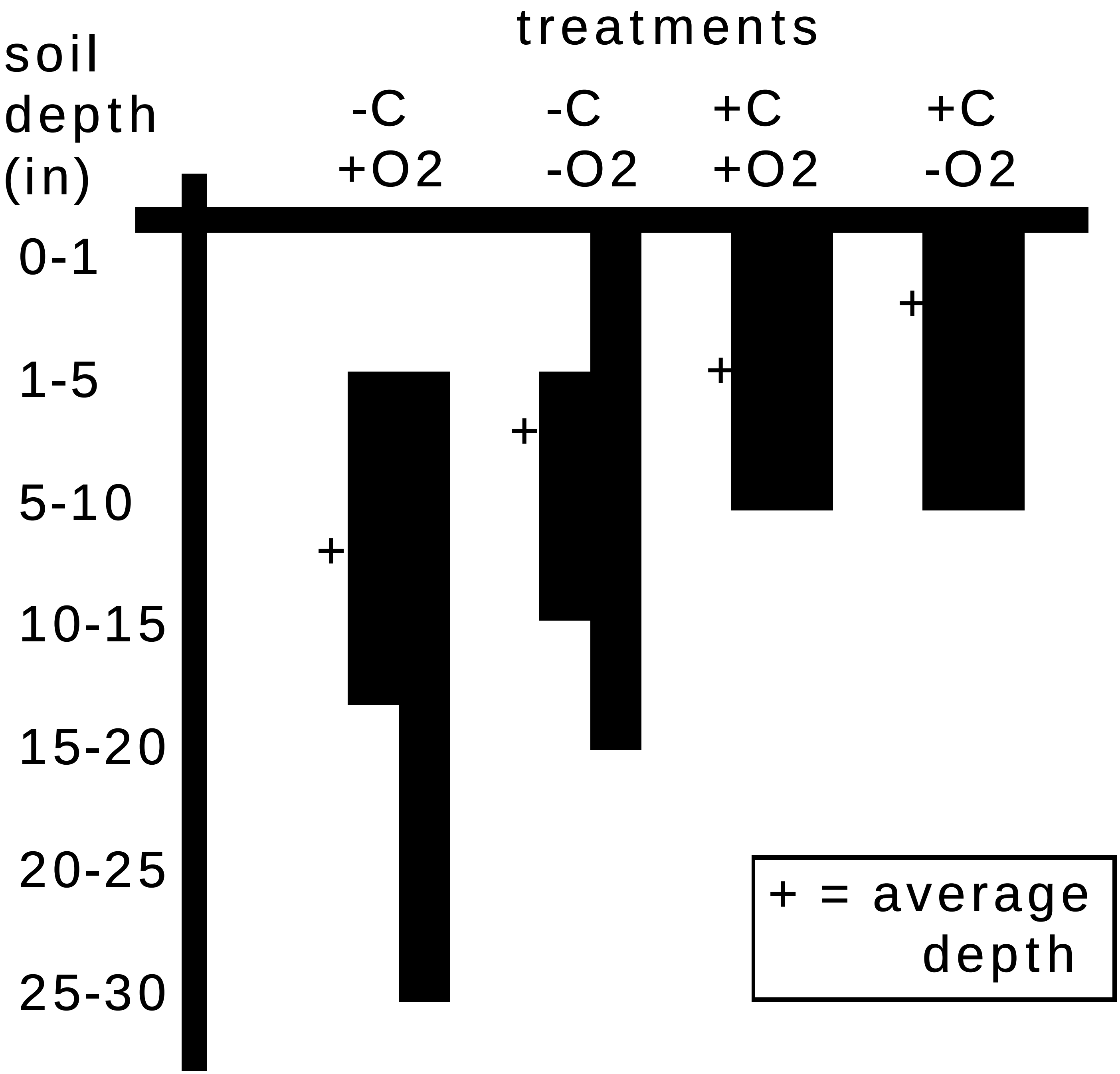

Figure 4: Compaction (+ 28%) and oxygen (- 5%) impacts on tree rooting depths. (after Gilman et.al. 1987)

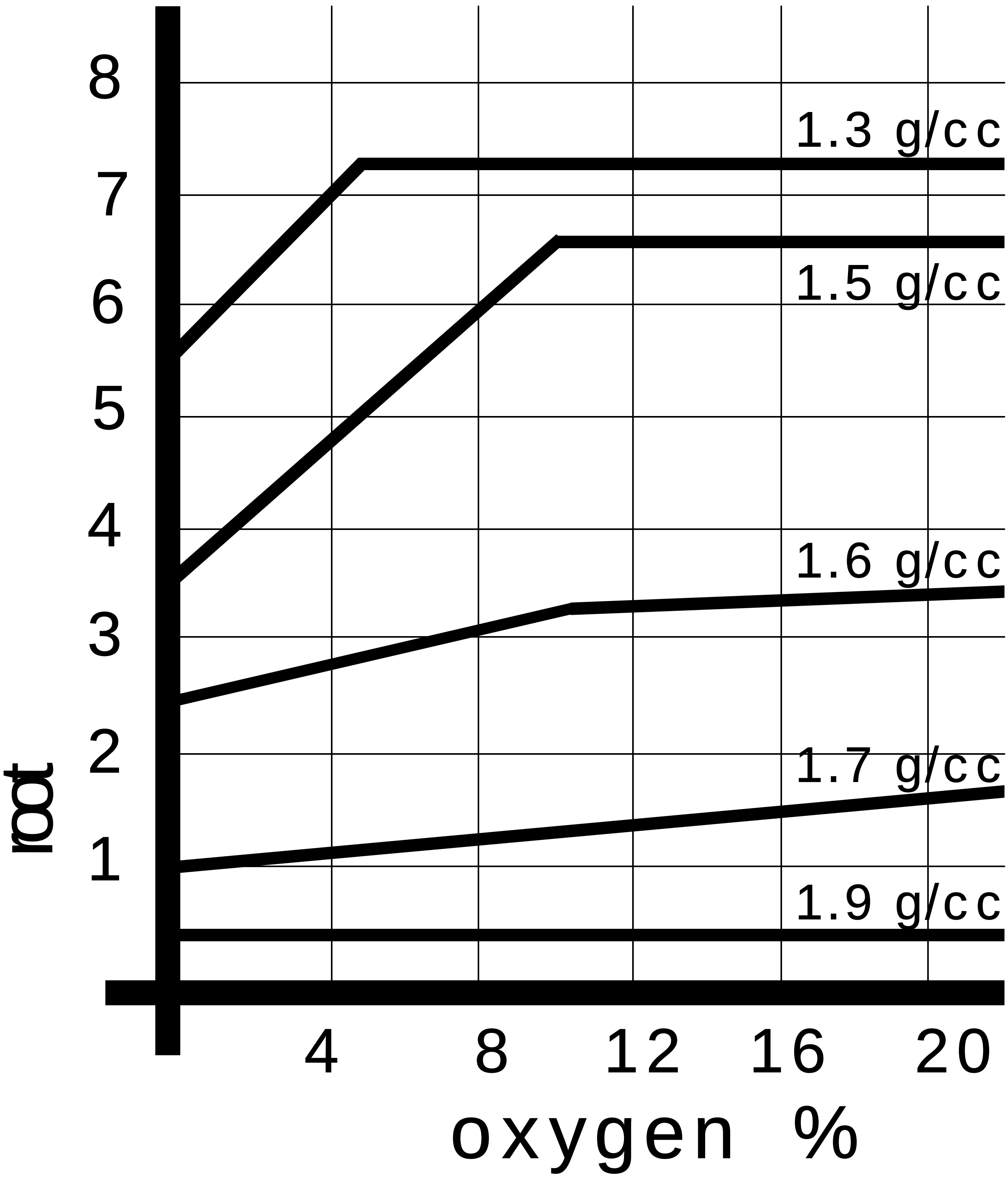

Figure 5: Percent oxygen and bulk density effects on root penetration. (after Rendig & Taylor 1989)

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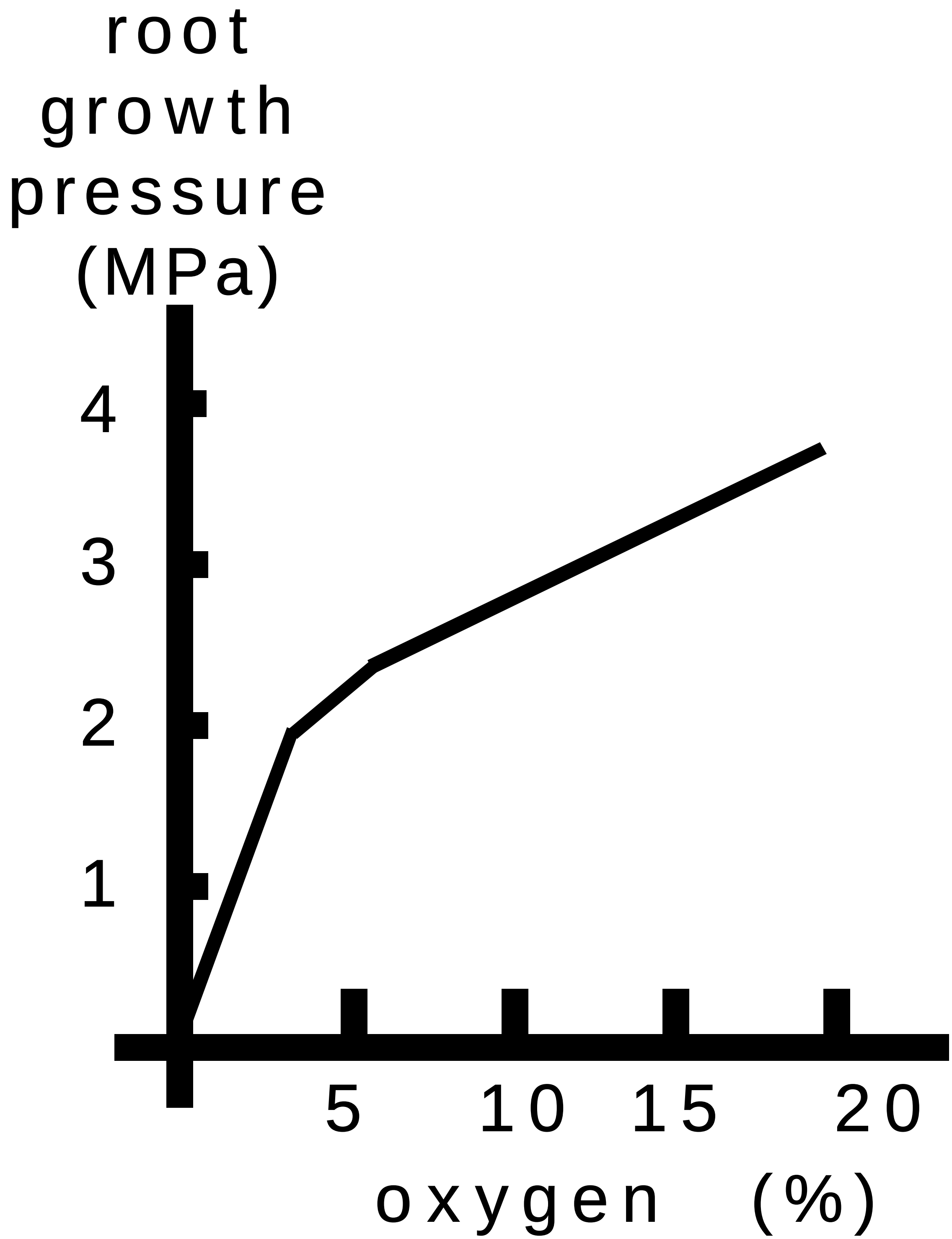

Figure 6: Root growth pressure by oxygen concentration.
(after Souty & Stepniewski 1988)

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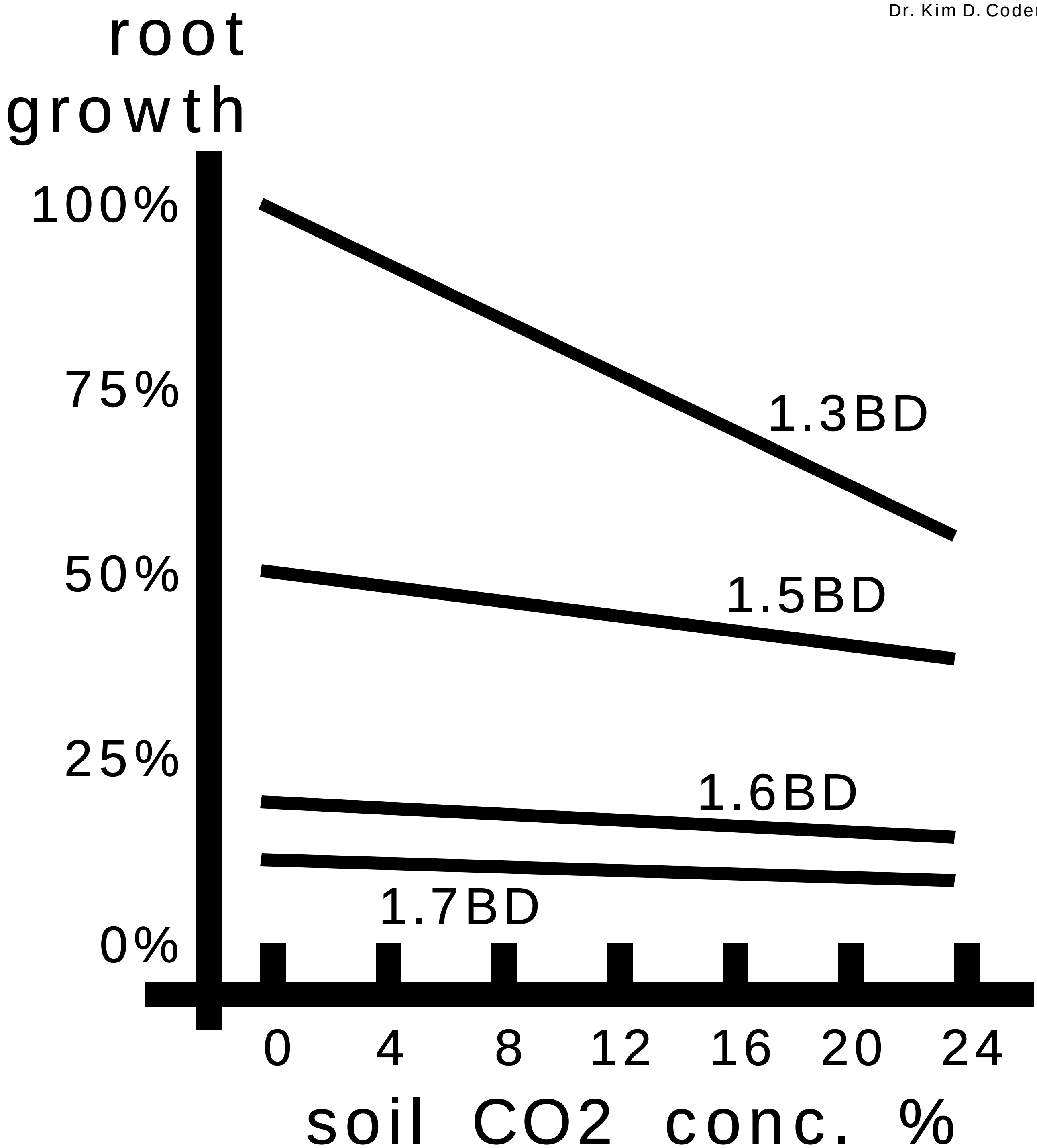

Figure 7: Carbon dioxide (CO_2) concentrations in the soil and bulk density impacts on root growth. (after Patterson)

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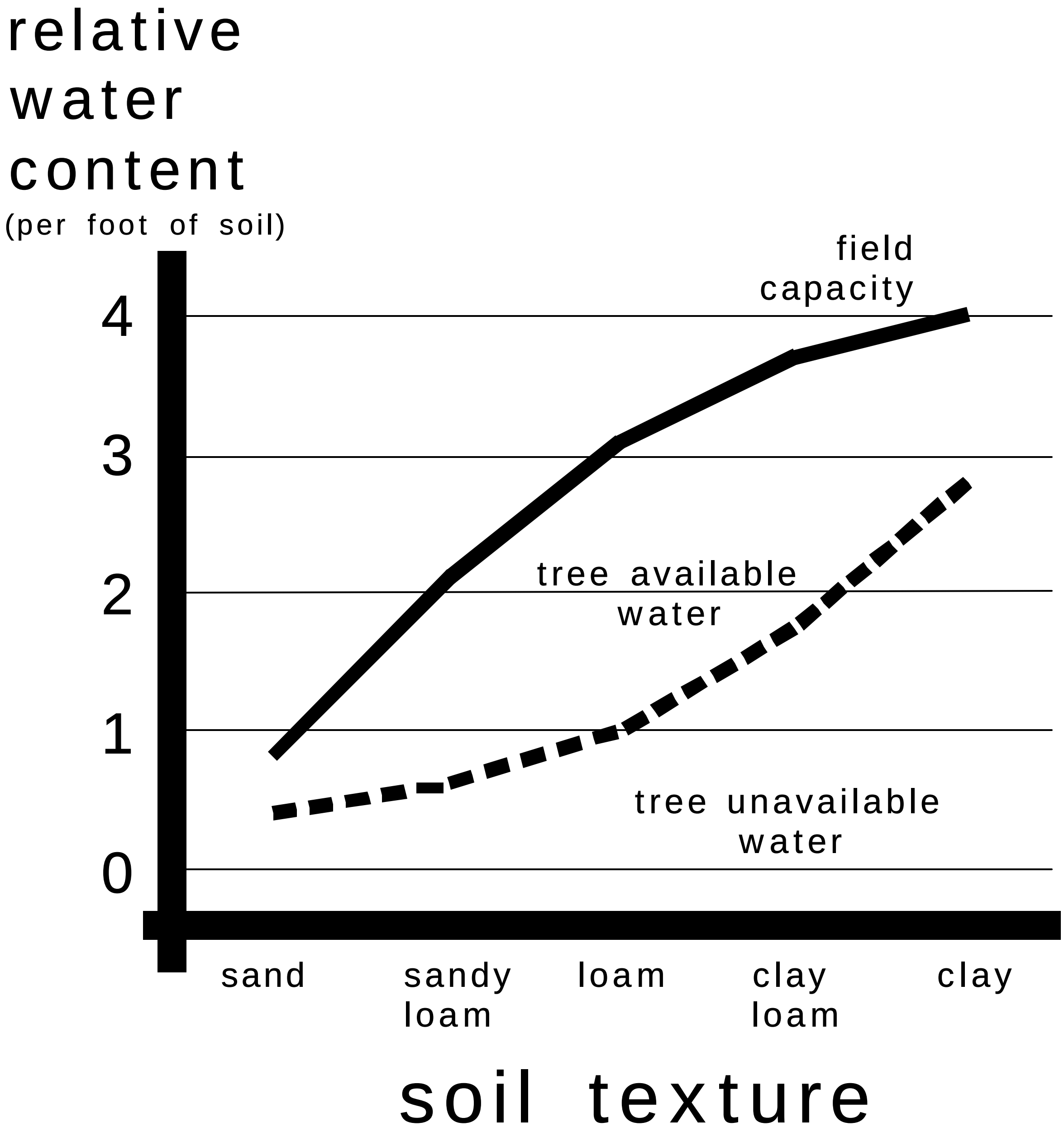

Figure 8: Tree-available water present at different soil textures.

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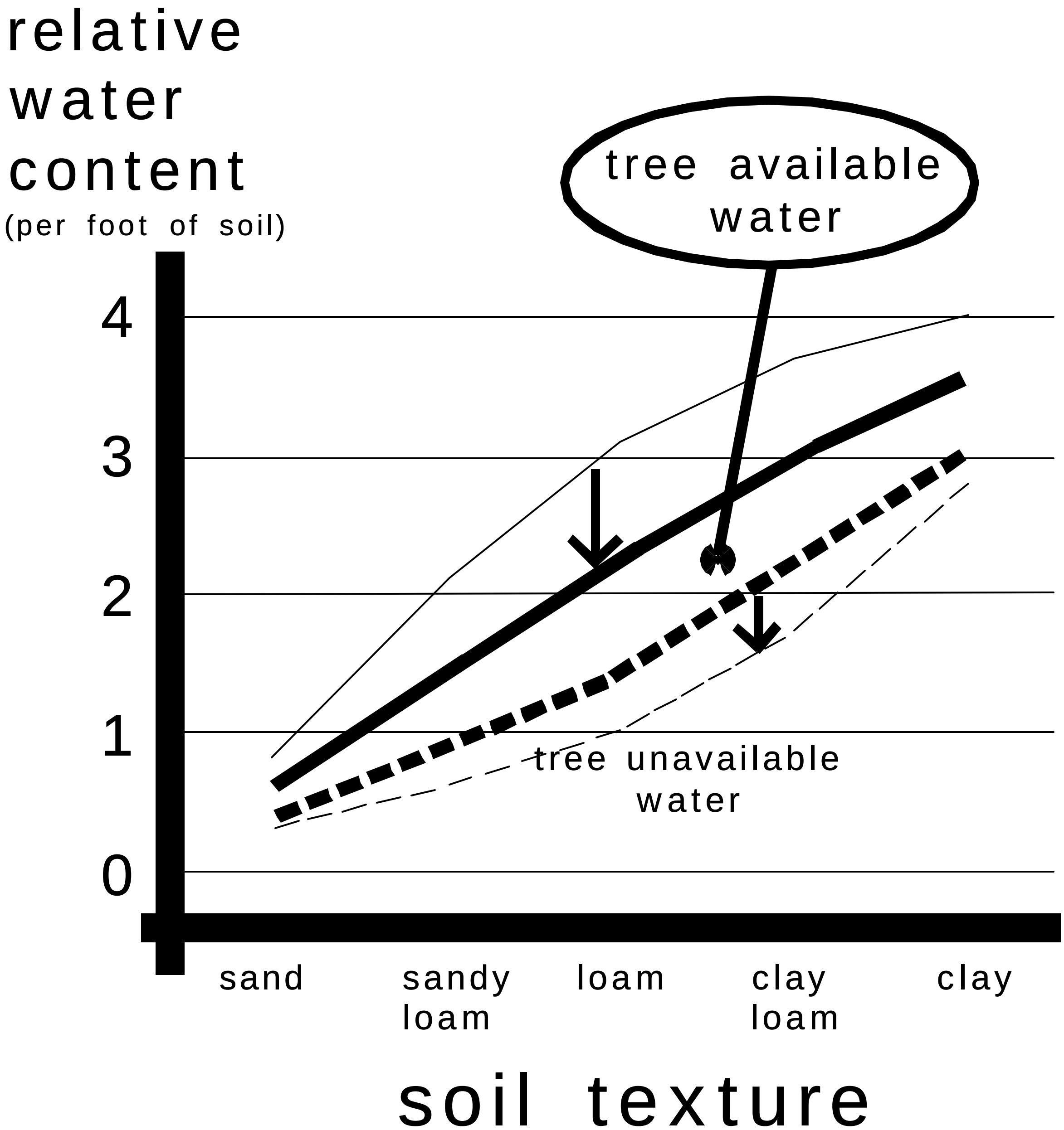

Figure 9: Tree-available water present at different soil textures under compaction.

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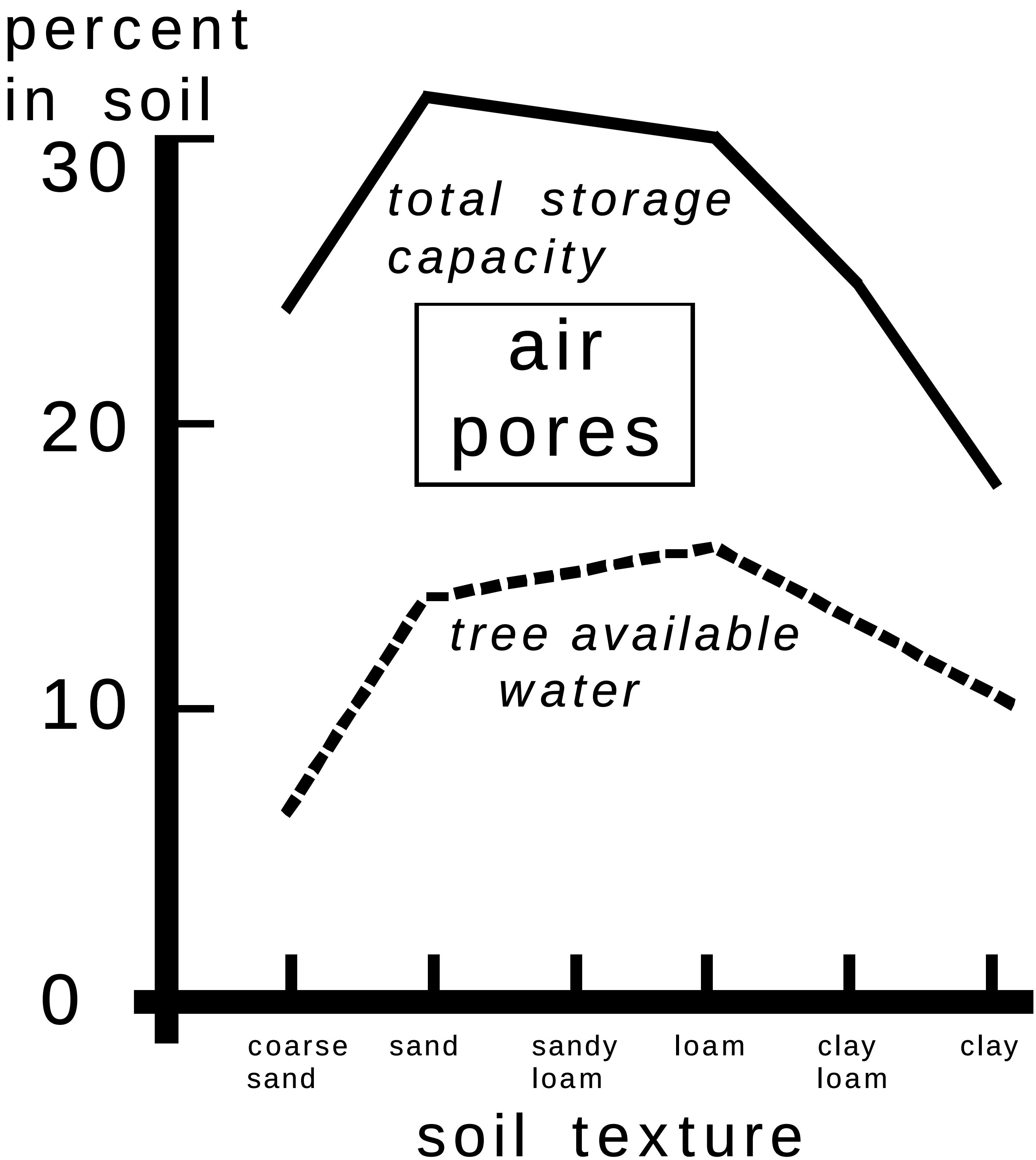

Figure 10: Water storage capacity in normal soil. (after Craul 1999)

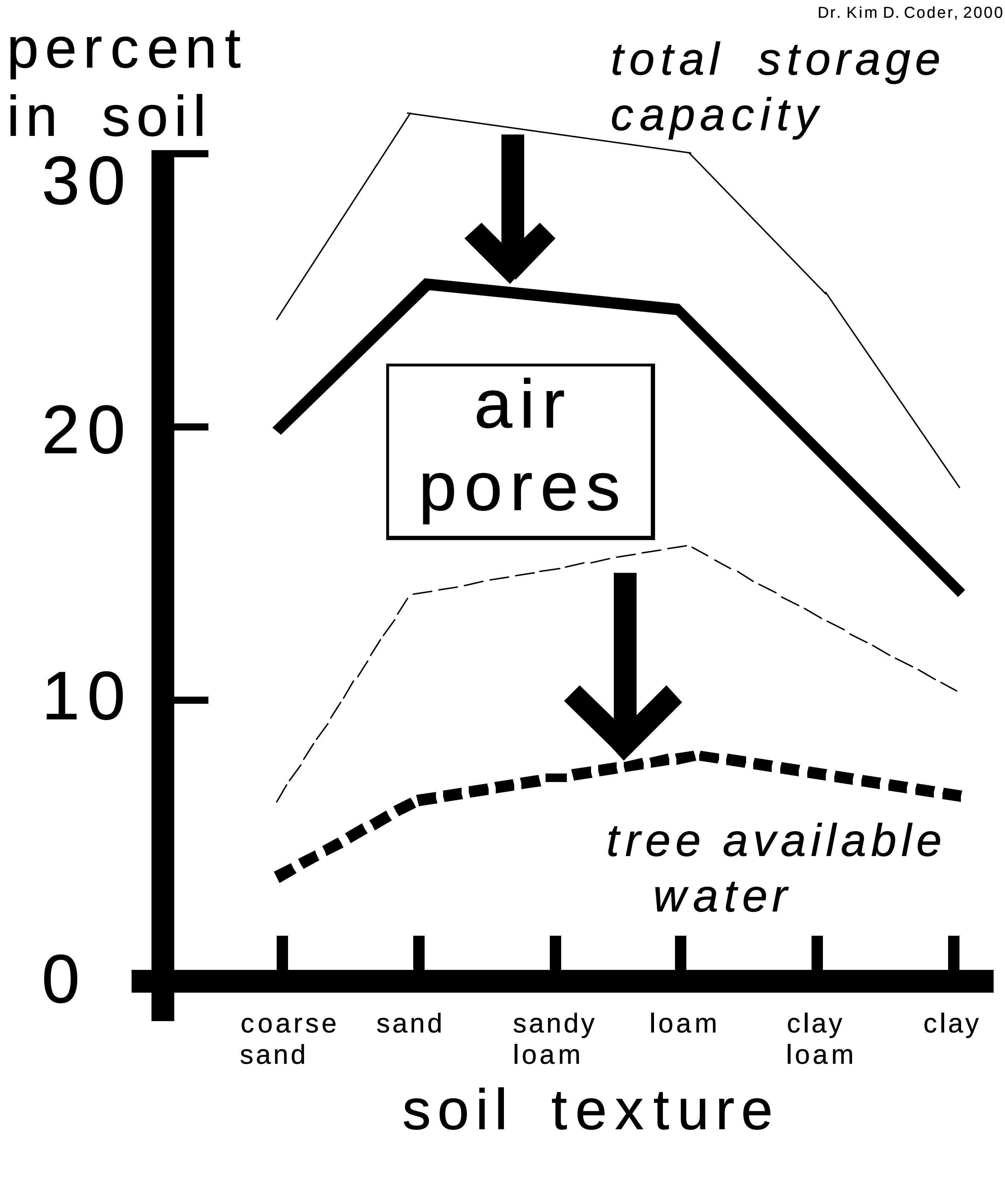

Figure 11: Water storage capacity under compaction. (after Craul 1999)