# Tree Root Growth Requirements

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

Roots utilize space in the soil. The more space controlled the more potential resources controlled. The volume of soil space controlled by tree roots is directly related to tree health. The resources required are water, oxygen, physical space for growth processes, and open soil surface area for replenishment of essential resources. Tree roots occupy the spaces and gaps around, under, and between infrastructures. In heavily compacted sites, roots will be concentrated around the edges of infrastructures and filling any moist air space. The soil matrix is only a significant concern for essential elements, surfaces holding biological cooperators, and frictional and inertial forces for structural integrity. Figure 1.

Tree roots and the soil surrounding them are an ecological composite of living, once-living, and abiotic features facilitating life. Compaction initiates many negative impacts in the soil including: decreases the volume of ecologically active space available; tree rootable space is decreased and made more shallow; the detritus food web, the ecological engine responsible for powering a healthy soil, is disrupted and modified; the diversity of living things decline, beneficial associates are eliminated, and a few ecological niche generalists succeed; and, pests favored by the new conditions (i.e. Pythium & Phytophthora) consume organisms and roots not able to defend themselves. Tree roots become more prone to damage and attack at a time when sensor, defense, growth regulation, and carbon allocation processes are functioning at reduced levels.

## Root Requirements

Growth in trees may not be a positive increase in living mass, but does represent expansion of tissues into new spaces. For roots, the tips elongate and the tissues thicken in diameter. Lateral roots are developed adventitiously and allowed to elongate and radially thicken. Root density, mass, and activity vary with internal and external conditions. Resources required for root growth are summarized in Table 1.

Roots utilize soil spaces for access to water and essential element resources, and to provide structural support. Roots grow following pathways of interconnected soil pores. Pore space can be the result of the space between textural units (sand, silt, and clay particles), between structural units (blocks, plates, grains, prisms, etc.), along fracture lines (shrink / swell clays, frost heaving, pavement interfaces, etc.), and through paths of biological origins (decayed roots, animal diggings, etc.).

Roots survive and grow where adequate water is available, temperatures are warm, and oxygen is present. Roots are generally shallow as limited by oxygen contents, anaerobic conditions, and water saturation in deeper soil. Near the base of the tree, deep growing roots can be found, but they are oxy-

The University of Georgia

THE UNIVERSITY OF GEORGIA, THE UNITED STATES DEPARTMENT OF AGRICULTURE AND COUNTIES OF THE STATE COOPERATING . THE COOPERATIVE EXTENSION SERVICE OFFERS EDUCATIONAL PROGRAMS, ASSISTANCE AND MATERIALS TO ALL PEOPLE WITHOUT REGARD TO RACE, COLOR, NATIONAL ORIGIN, AGE, SEX OR HANDICAP STATUS. A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA. AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION ORGANIZATION

UNIVERSITY OF GEORGIA WARNELL SCHOOL OF FOREST RESOURCES EXTENSION PUBLICATION FOR00-5
WEB Site = WWW.FORESTRY.UGA.EDU/EFR

genated through fissures and cracks generated as a result of mechanical forces moving the crown and stem under wind loads (sway).

## Growth Forces

The ability of primary root tips to enter soil pores, further open soil pores, and elongate through soil pores is dependent upon the force generated by the root and the soil penetration resistance. Root growth forces are generated by cell division and subsequent osmotic enlargement of each new cell . Oxygen for respiration, and adequate water supplies are required. Figure 2. Tree roots can consume large amounts of oxygen during elongation. At 77°F (25°C) tree roots will consume nine times their volume in oxygen each day, at 95°F (35°C) roots can use twice that volume per day. The osmotic costs to cells of resisting surrounding forces and elongating can be significant.

In response to increased compaction, roots thicken in diameter. Compaction also forces roots to generate increased turgor pressures concentrated farther toward the root tip, to lignify cell walls quicker behind the growing root tip, and to utilize a shorter zone of elongation. Thicker roots exert more force and penetrate farther into compacted soil areas. Figure 3. As soil penetration resistance increases in compacted soils, roots thicken to minimize their own structural failure (buckling), to exert increased force per unit area, and to stress soil just ahead of the root cap which allows for easier penetration.

For effective root growth, pore sizes in the soil must be larger than root tips. With compaction in a root colonization area, pore space diameters become smaller. Once soil pore diameters are less than the diameter of main root tips, many growth problems can occur. The first noticeable root change with compaction is morphological. The main axis of a root becomes thicker to exert more force to squeeze into diminished sized pores. As roots thicken, growth slows and more laterals are generated of various diameters. Lateral root tip diameters are dependent upon initiation by growth regulator and the extent of vascular tissue connections. If laterals are small enough to fit into the pore sizes of the compacted soil, then lateral growth will continue while the main axis of the root is constrained. If the soil pore sizes are too small for even the lateral roots, root growth will cease. Figure 4.

## Tree Species Tolerance

Across the gene combinations which comprise tree forms, there is a great variability in reactions to soil compaction. As there are many different soils and associated responses to compaction, so too are there many gradations of tree responses to compaction. A tree's ability to tolerate compacted soil conditions is associated with four primary internal mechanisms: reaction to mechanical damage is effective and fast; continuation of respiration under chronic O2 shortages; ability to continue to turnover, reorient, and adjust absorbing root systems; and, ability to deal with chemically reduced materials (toxics).

A list of trees meeting the above criteria for soil compaction tolerance can be found in: *Coder, Kim D. 2000. **Compaction Tolerant Trees.** University of Georgia School of Forest Resources Extension Publication FOR00-2. 1pp. (Download at WEB site www.forestry.uga.edu/efr under "tree health care.")*

## Conclusions

Tree roots and soil are a cooperative venture which generates healthy trees and healthy soils. Understanding how root grow and utilize soil is critical to proper tree management.

Table 1: Brief list of root growth resource requirements.

| root resource | requirements minimal | maximum |
|---|---|---|
| oxygen in soil atmosphere (for root survival) | 3% | 21% |
| air pore space in soil (for root growth) | 12% | 60% |
| soil bulk density restricting root growth (g/cc) | - | 1.4 clay |
| | - | 1.8 sand |
| penetration strength (water content dependent) | 0.01kPa | 3MPa |
| water content in soil | 12% | 40% |
| root initiation (O2% in soil atmosphere) | 12% | 21% |
| root growth (O2% in soil atmosphere) | 5% | 21% |
| progressive loss of element absorption in roots (O2% in soil atmosphere) | 10% | 21% |
| temperature limits to root growth | $40^{o}$F/$4^{o}$C | $94^{o}$F/$34^{o}$C |
| pH of soil (wet test) | pH3.5 | pH8.2 |

Dr. Kim D. Coder, 2000

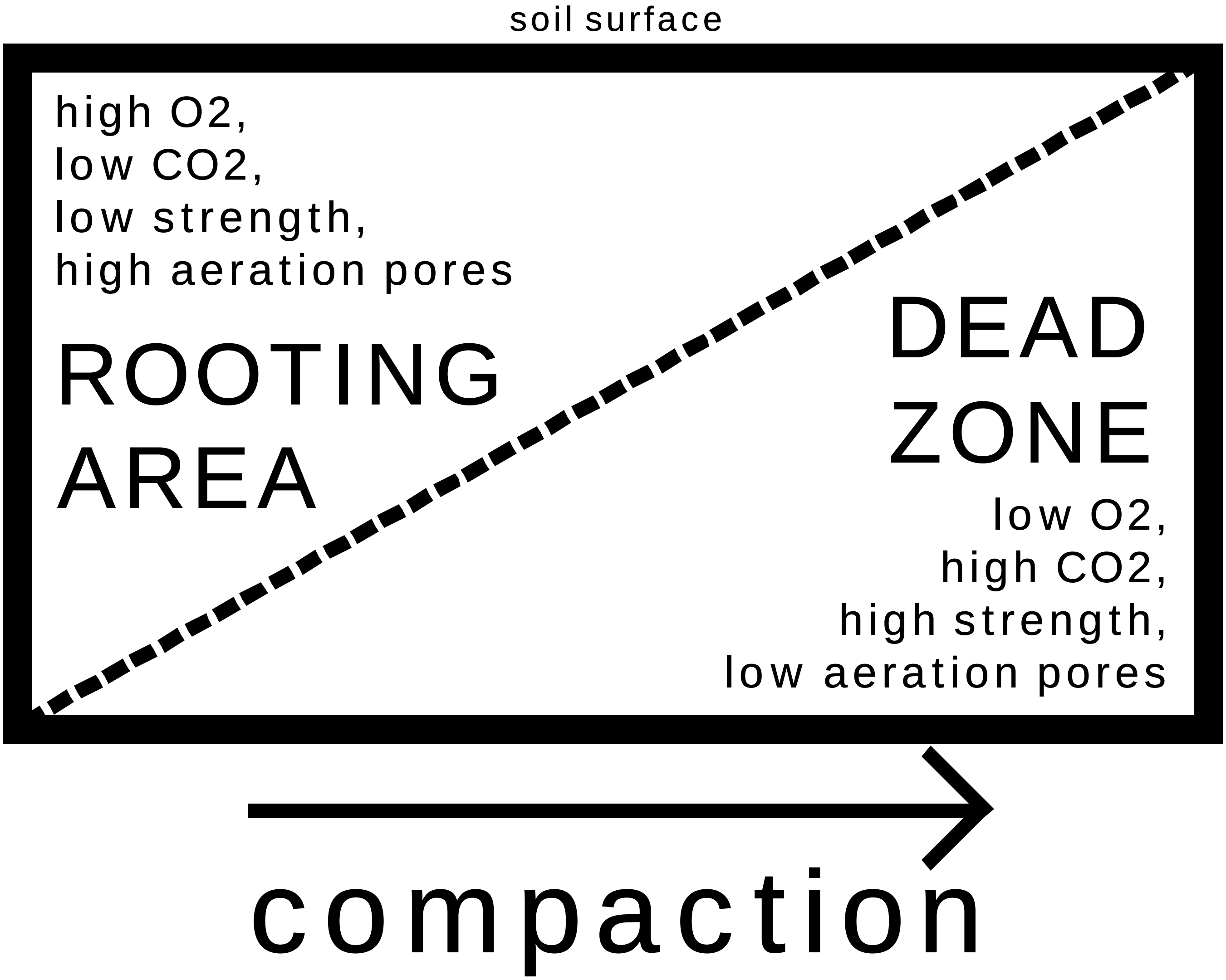


Figure 1: Graphical representaion of compaction effects on soil.

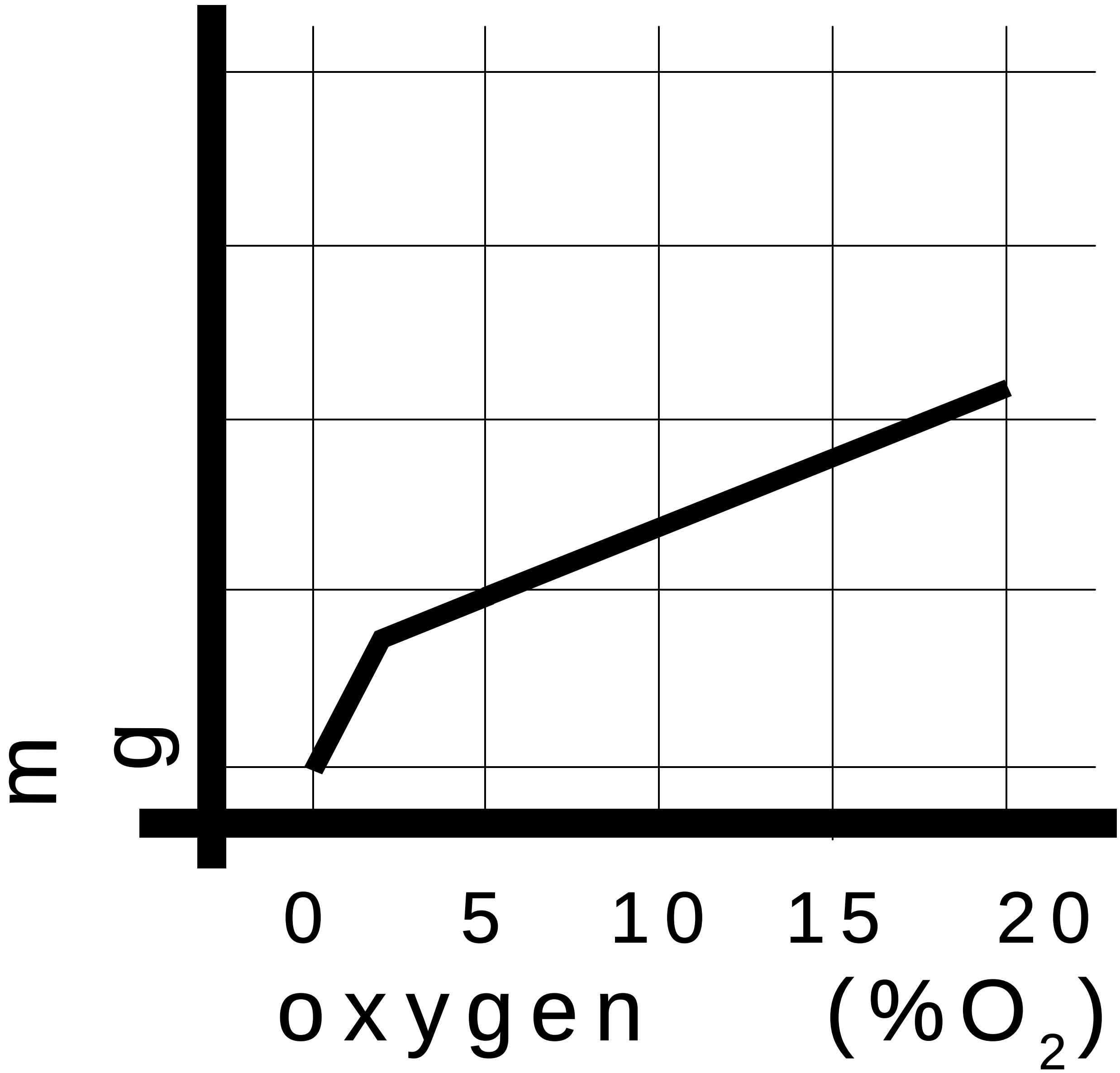


Figure 2: Maximum root growth force expressed by seedlings at various oxygen concentrations.
(after Souty & Stepniewski 1988)

Dr. Kim D. Coder, 2000

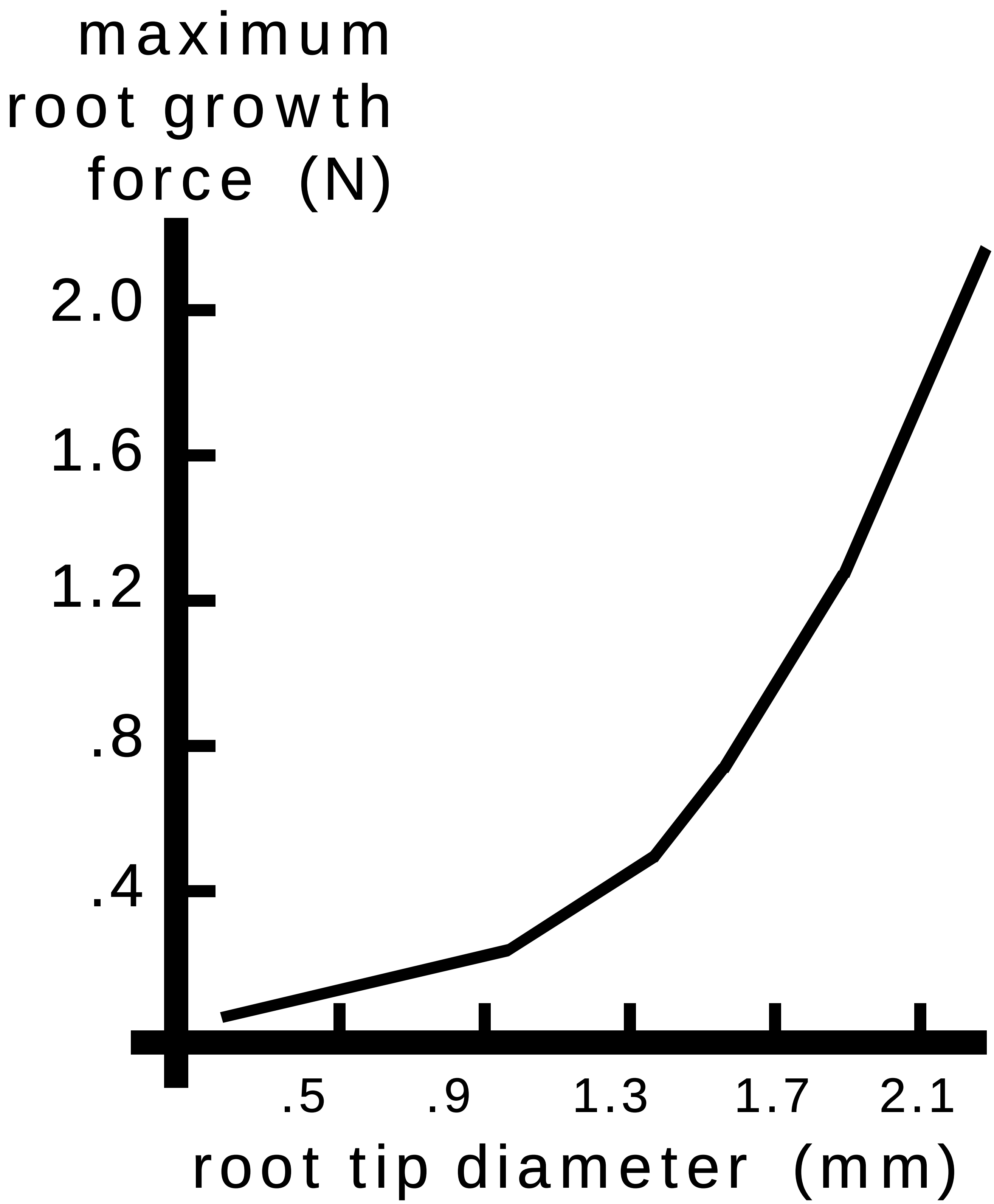


Figure 3: Maximum root growth force by root tip diameter.
(after Misra et.al. 1986)

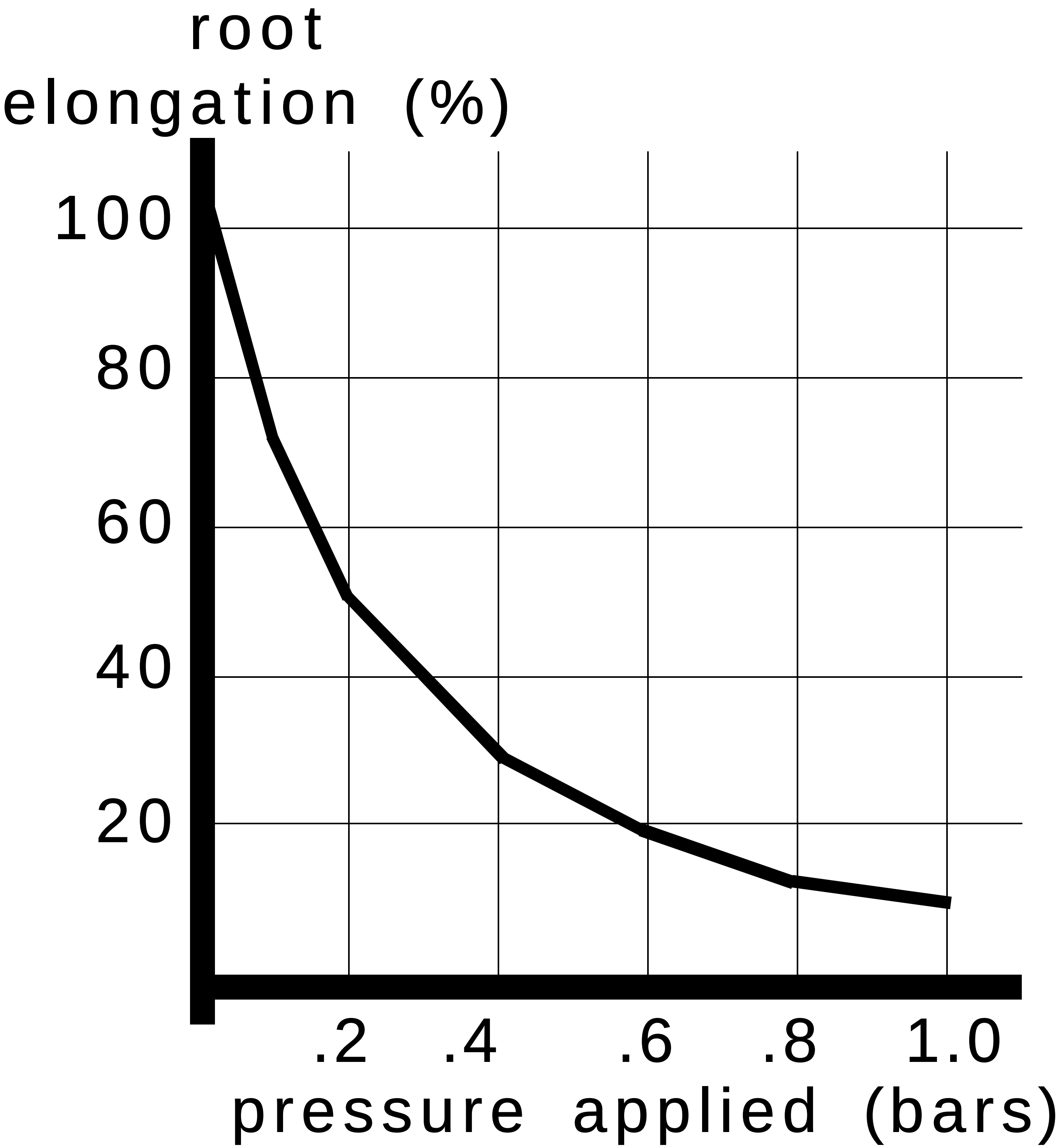


Figure 4: Pressure applied to roots that limit elongation.
(after Rendig & Taylor 1989; Russell, 1977) (1 MPa =100 kPa ▪ 1 bar)