Street-tree performance in suspended pavements:
Tree growth, health, results.

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TREE FUND
Cultivating Innovation

Tree Requirements

5. Room for canopy growth

6. Quality nursery stock

Trunk Flare

2.

3. Water in

1. ***Sufficient Soil Volume Under pavement***

4. Water out

Zone of rapid root taper

OPTIONS CONSIDERD

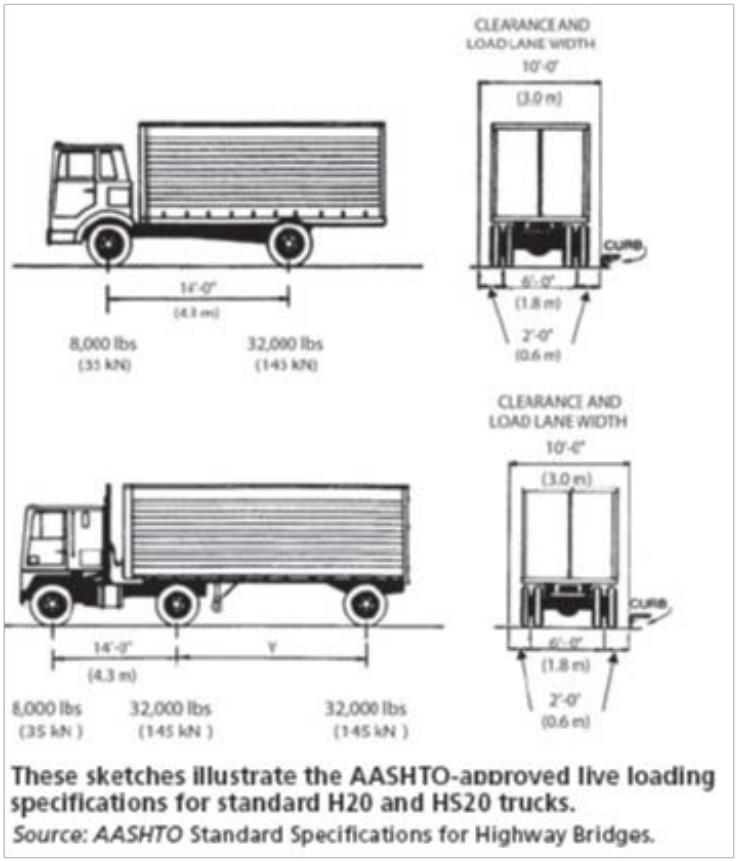
Suspended Pavement:
Silva Cells (post and beam soil cells)

Stratacells (segmented soil cells)

Structural Growing Media:
Gravel Based Structural Soils

Compacted Sand Structural Soil

LOAD BEARING DEFINED



These sketches illustrate the AASHTO-approved live loading specifications for standard H20 and HS20 trucks.

Source: AASHTO Standard Specifications for Highway Bridges.

Spanning Structures

AASHTO H-20 Loading

145kN (32,000 lb) load

Pavement subbase

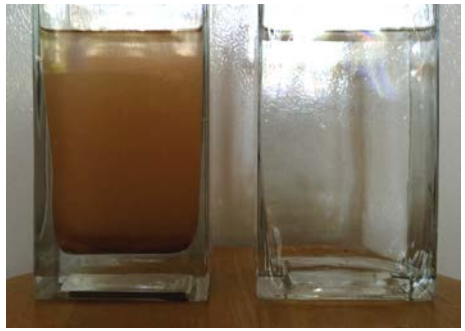
Standard Proctor Test

95% of Maximum Dry Density

RELATED FACTORS IN THE EVALUATION OF AN OPTION

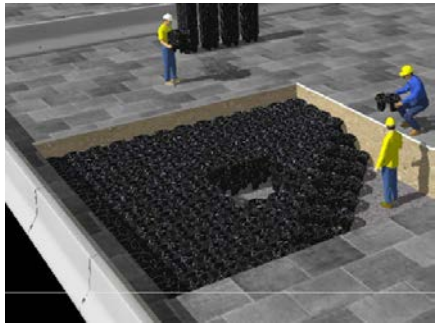
Storm water

Quality / quantity.



Layout flexibility

Conflicts with existing
and proposed structures,
and dimensional variations
within the design.



Volumetric effectiveness

Effective **loam soil volume**.

Does each approach provide
Equivalent loam soil volume
in the same space?

RELATED FACTORS IN THE EVALUATION OF AN OPTION

Soil limitations

Unscreened Loam vs Screened Loam Vs Sand soils

Unscreened loam soil

Screened loam soil

Manufactured sand soil

Existing soils

Soil beyond the system supporting pavement

Large trees in compacted soil

Rooting soil under parking lot

Deep rooting resource

Water harvesting

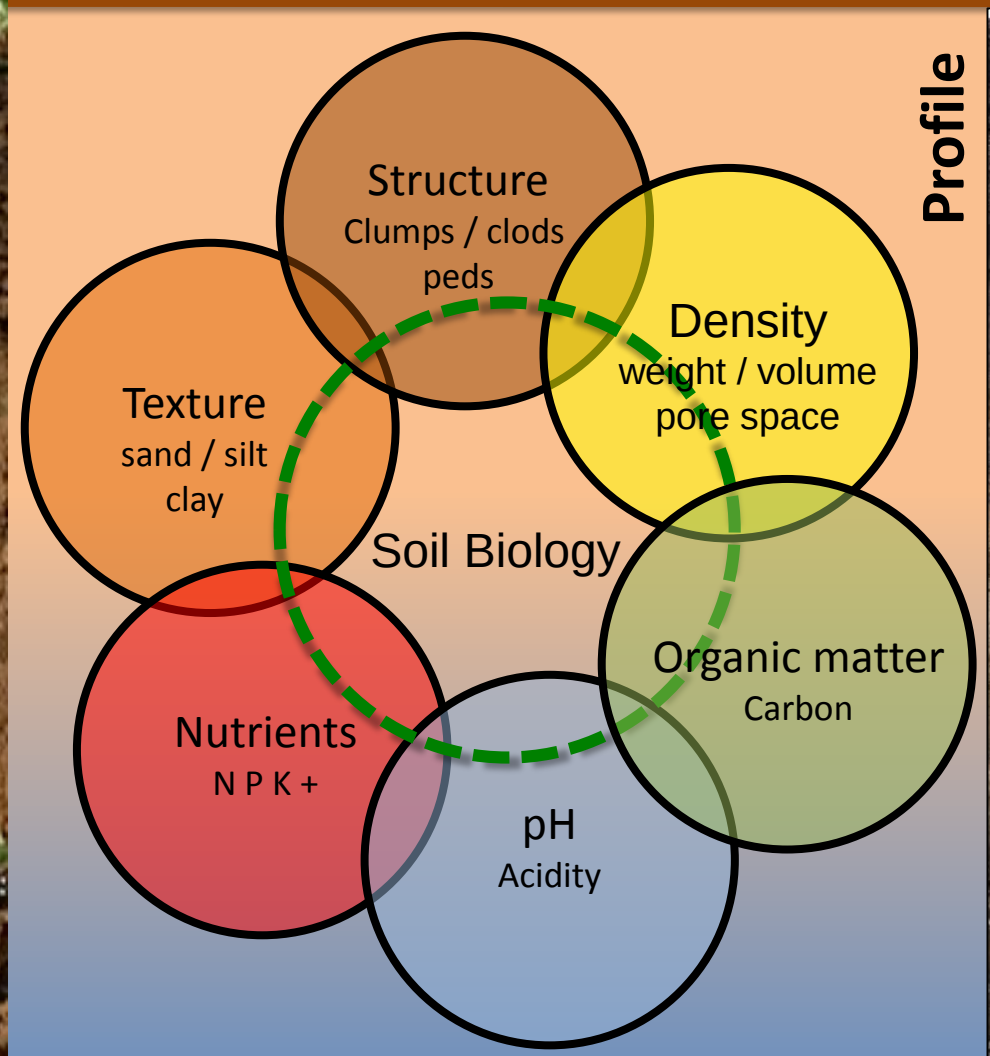
Water into the system

Pervious pavers

Clogged water access

Sub-paving distribution

Critical Aspects of Soil

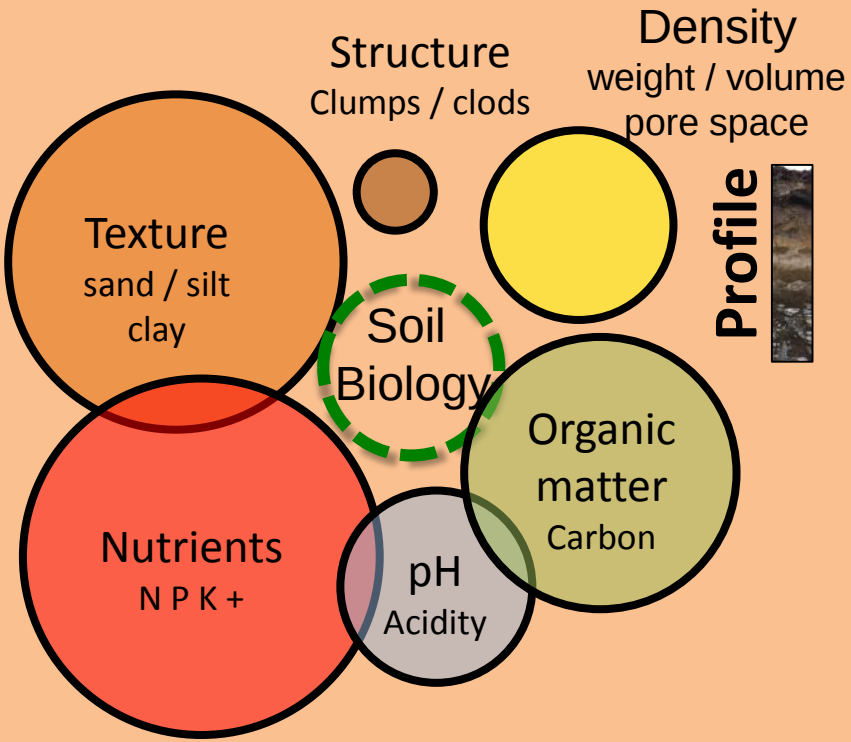


Profile

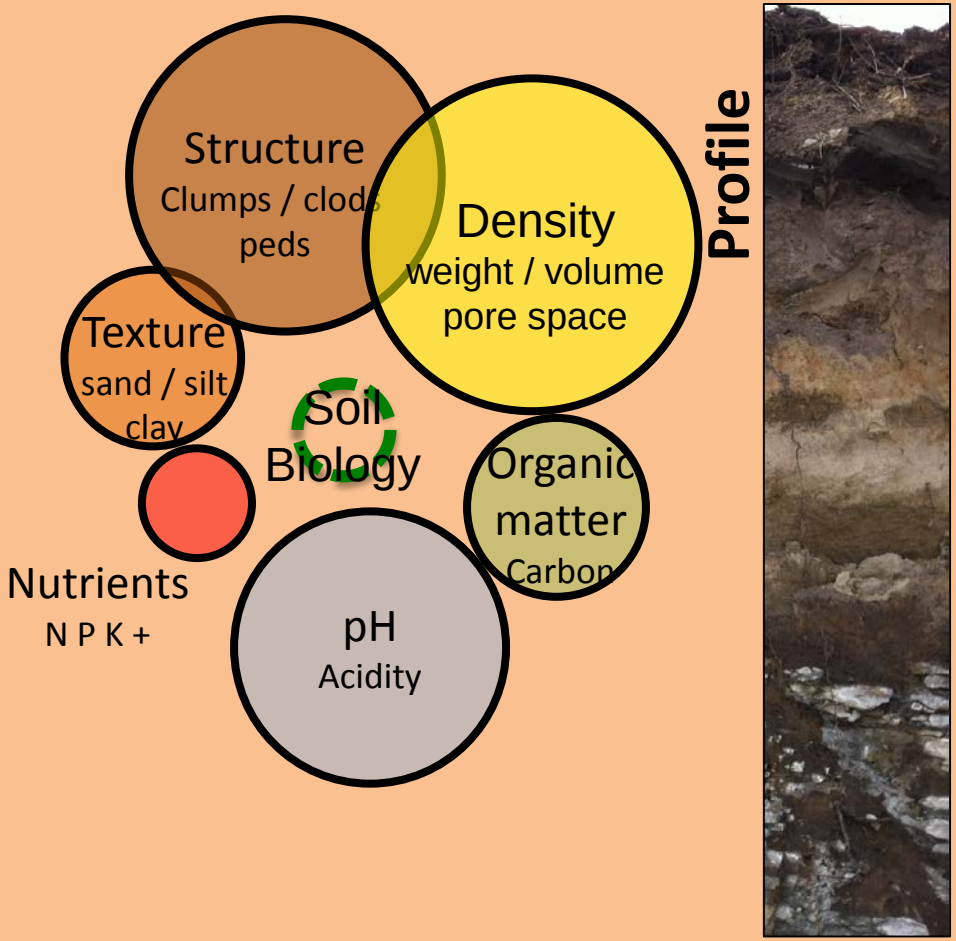
What is good soil?

Critical Aspects of Soil

Traditional levels of importance



Proposed levels of importance



SOIL PROPERTIES RESEARCH

Soil structure / Screening / Soil ped preservation

Thesis: *Increasing the amount of unscreened loam in soils mixes would improve plant performance and is more sustainable.*

Screened sand soil

Unscreened loam soil

Soil collection pile – are about 5 soil type in this section

Sandy silt loam above:
Organic loam A horizon below

Typical gravel till

Local PNW Soils

Soil settlement (or shrinkage?) in high organic soils

COMPARATIVE RESEARCH AND ANALYSIS

26 research papers, and conference presentations

Controlled research plots
and
Monitoring / analysis of trees planted in built landscape projects.

SOIL PROPERTIES RESEARCH

Loam soil vs Manufactured soil

Higher sand content reduces tree growth

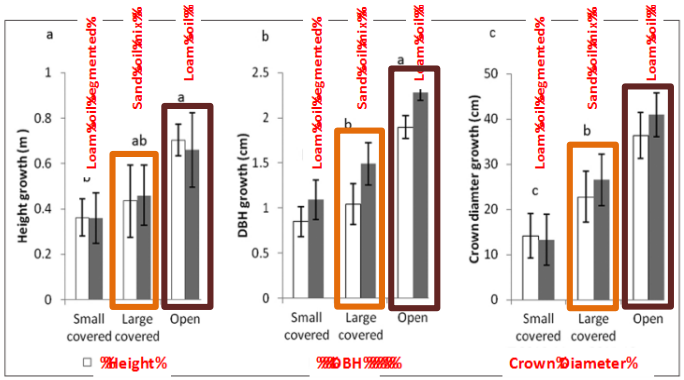
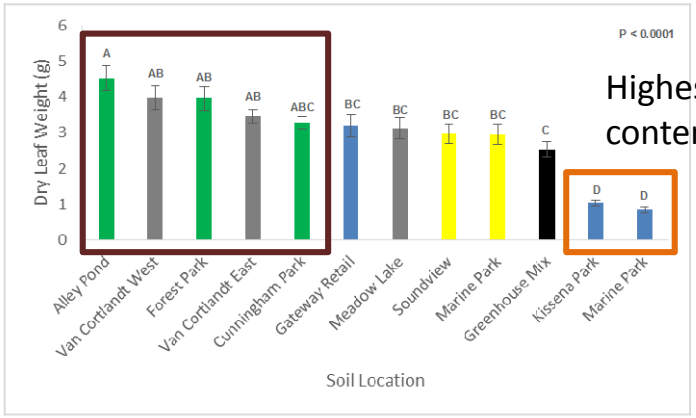


Figure 2. Annual growth rate in *Pyrus calleryana* trees grown in the three pit types in 2010–2012 (n = 5): (a) height, (b) DBH, (c) crown diameter increment.

Rhamen 2013



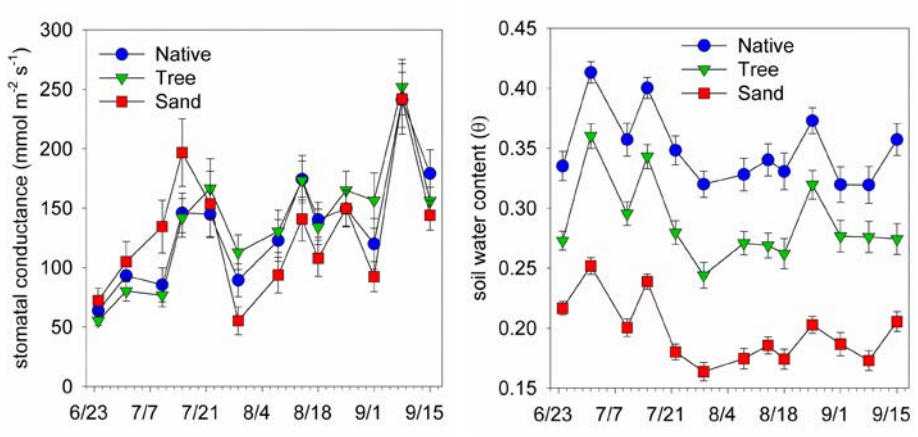
Highest sand content

Native Till Coal Ash Clean Fill Urban Fill

Pregitzer 2014

Horticultural soil performed better than manufactured soils

Fite 2013

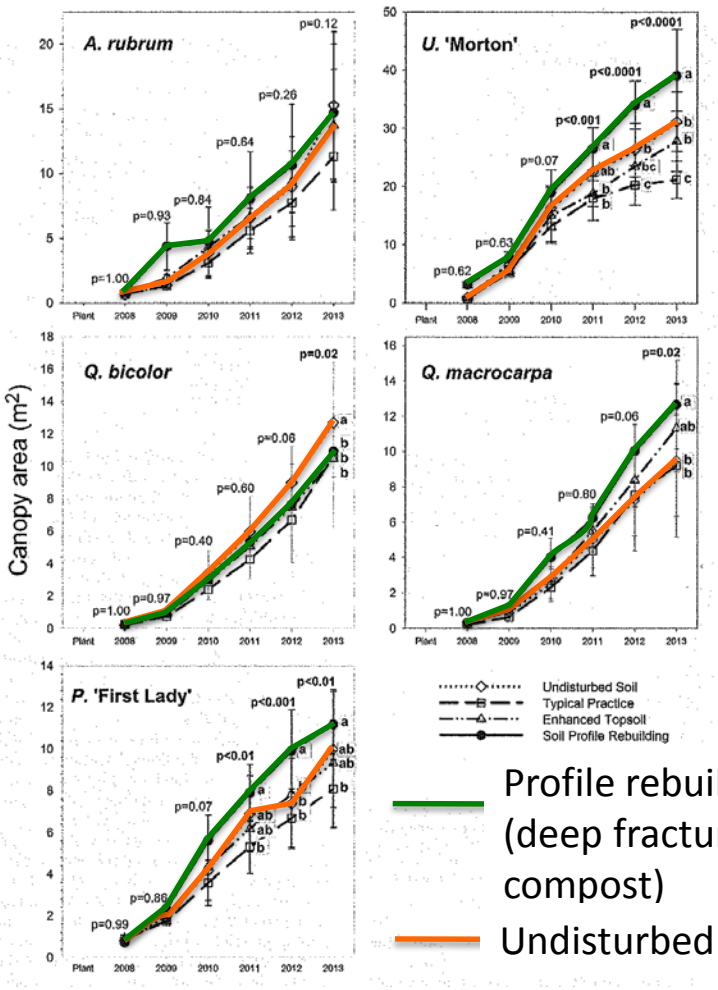


Urban 2015 (Scharenbroch, B)

SOIL PROPERTIES RESEARCH

Soil structure / Screening / Soil ped preservation

Preserving soil peds improves tree performance



Profile rebuilding (deep fracturing/ compost)

Undisturbed topsoil

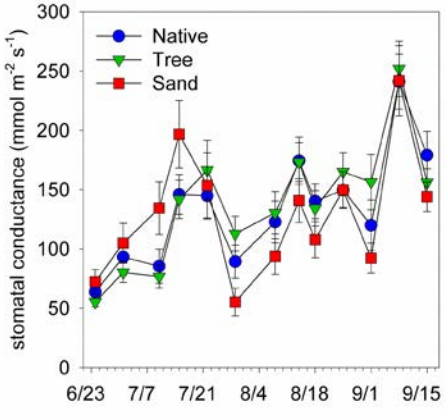
Soil Profile Rebuilding

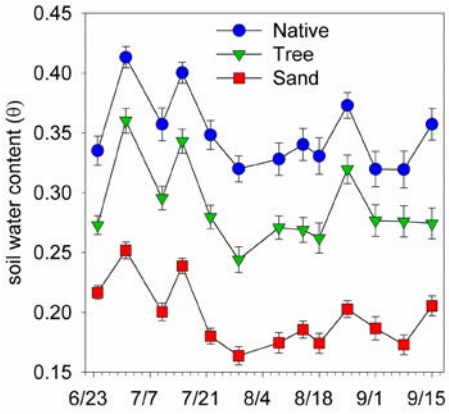
Layman et al 2016

Native Soil
100% topsoil 2”

Tree Soil
60% Topsoil 2”
15% Compost
25% Coarse Sand

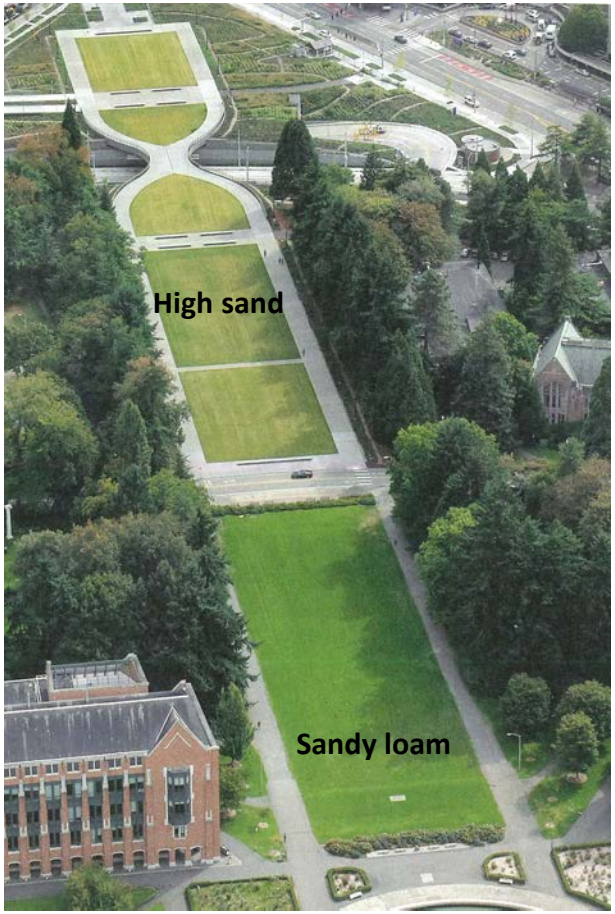
Sand Soil
25% Topsoil 3/8”
15% Compost
60% Coarse Sand

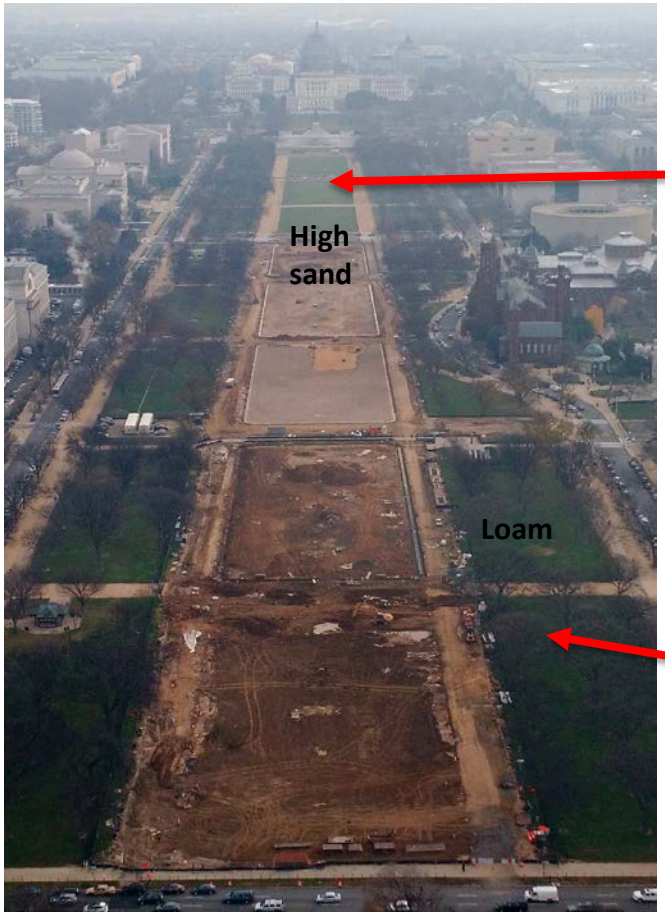


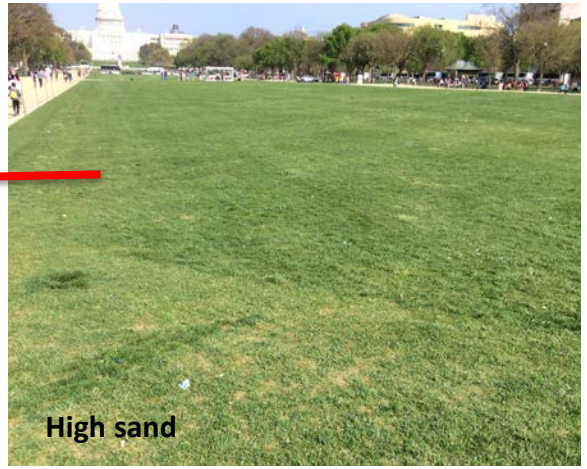


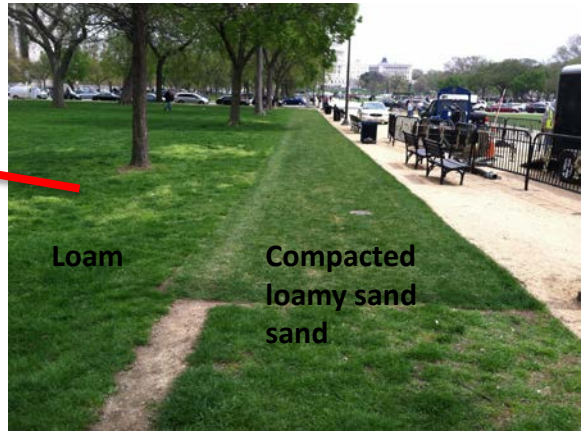
Soil screening and sand soil mixes

Urban 2015 (Scharenbroch, B)









High sand turf soil vs loam soil

CONCLUSIONS - Soil Volume:

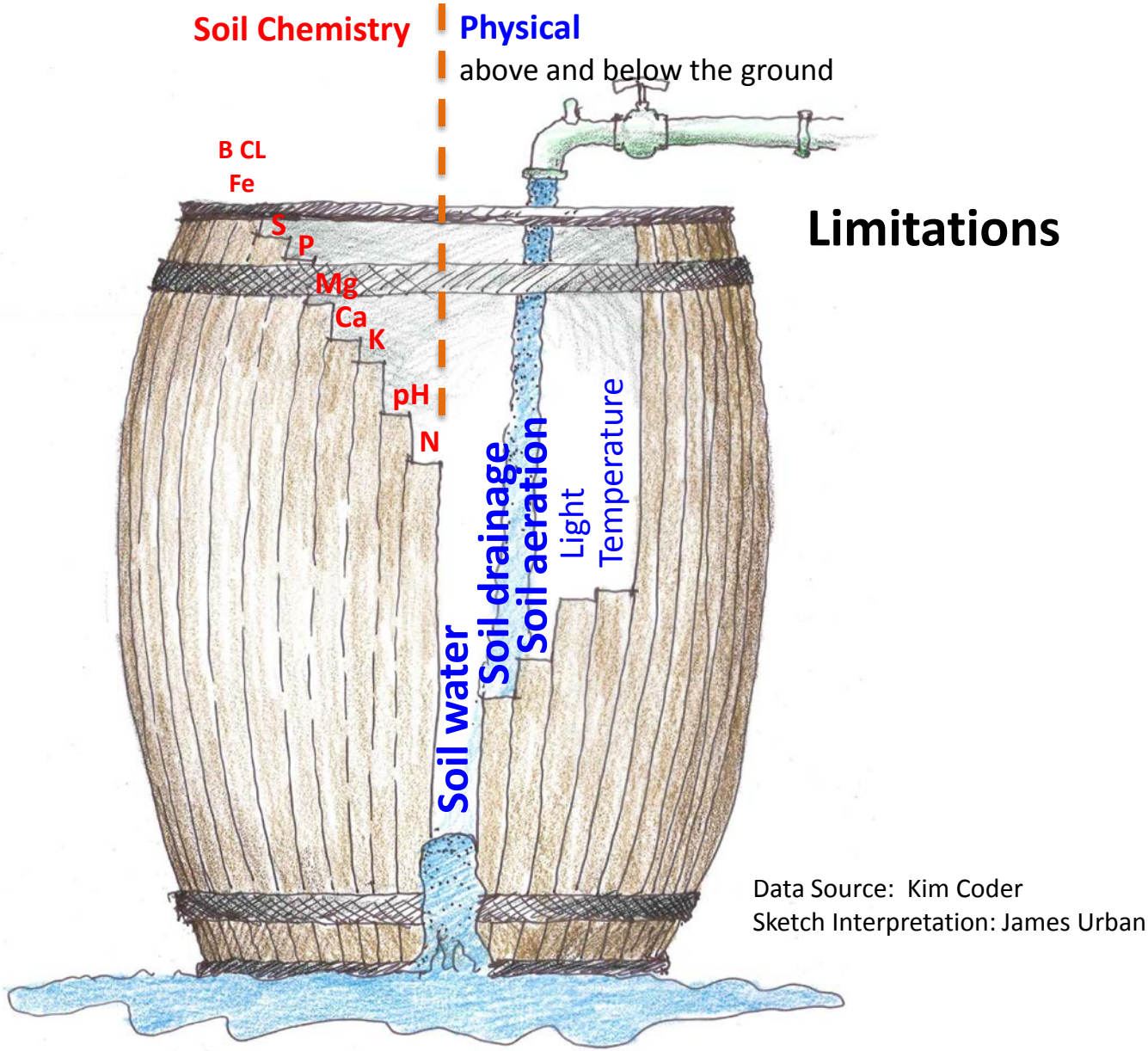
1. Soil volume to tree growth is based on **unscreened loam soils**. Compaction, or screening, blending, sandy soils or rocky soils will require greater amount of material to compensate for the growth limitations of these soils.

2. Evaluation efforts must account for the effect of **adjacent existing soils** in the overall amount of soil available to the tree.

SOIL PROPERTIES RESEARCH

Soil Chemistry and pH

Limited researched relative to load bearing soils

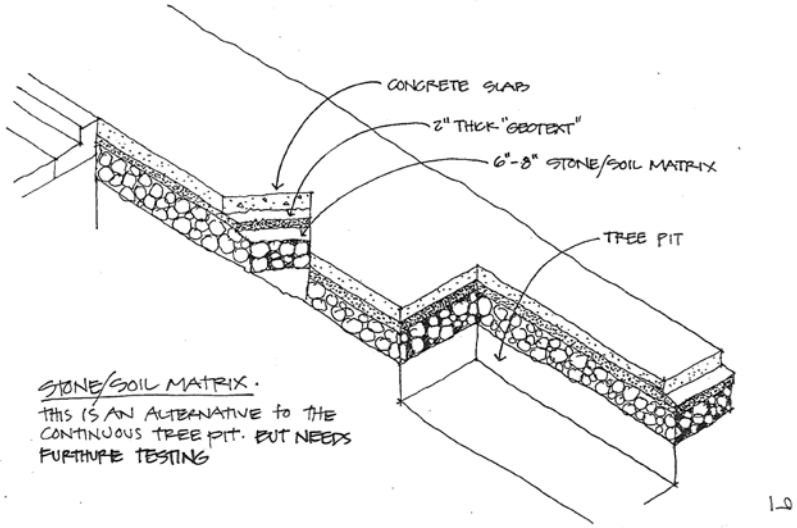


Data Source: Kim Coder

Sketch Interpretation: James Urban

RESEARCH SUSPENDED PAVEMENT SYSTEMS AND STRUCTURAL SOILS

Christian Science, Boston, MA, USA
The first suspended pavement project.
Sasaki Dawson Demay, Landscape Architects.
Planted 1975.



Original sketch for structural soil
By James Urban, FASLA
Presented at The Third National Urban Forestry Conference
Orland Florida, 1986.

RESEARCH STRUCTURAL SOIL SYSTEMS

Gravel based structural soil

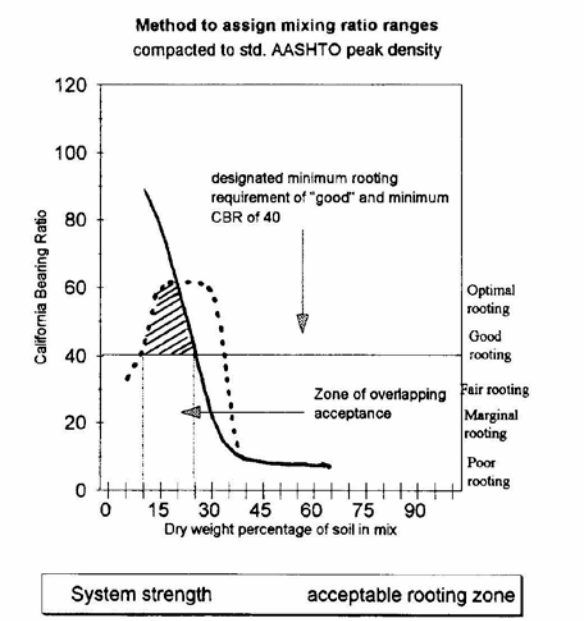
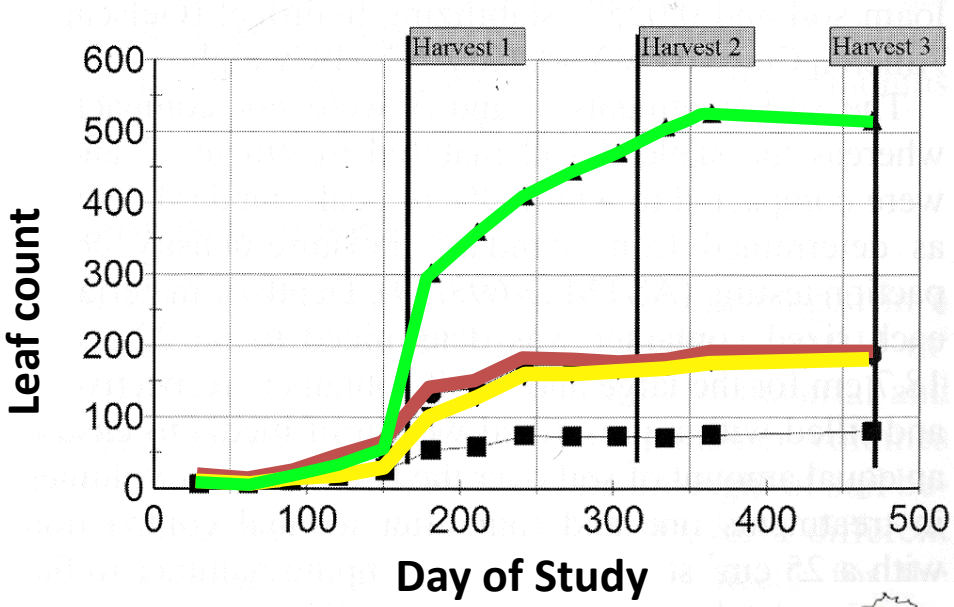


Figure 6. Acceptable CBR above 40 occurs when the soil is less than 25% of the mix. Rooting is acceptable when the soil is between 10% and 35%. The zone of overlapping acceptance then occurs when the soil is between 10% and 25% of the total mix by weight in this hypothetical example.

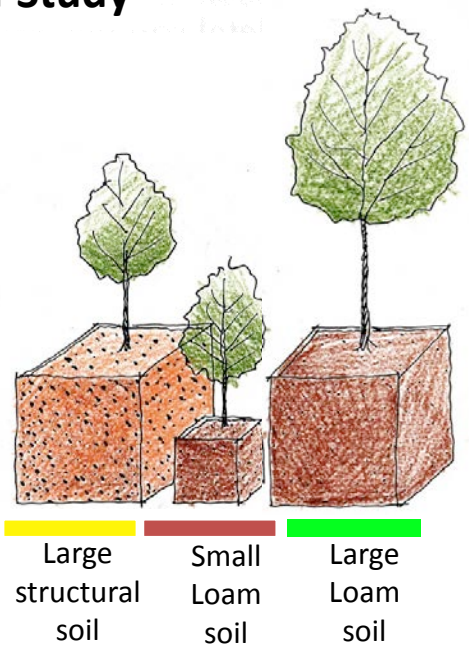
Mix ratio for gravel structural soil between 10 and 25% loam soil

Grabowski, J. 1996



Tree growth is limited by the content of the soil

Loh, F. 2003



RESEARCH STRUCTURAL SOIL SYSTEMS

Gravel based structural soil GBBS

Tree growth in GBBS made with brick or lava matched growth in sandy loam topsoil. Two-year container experiment with irrigation and fertilizer.

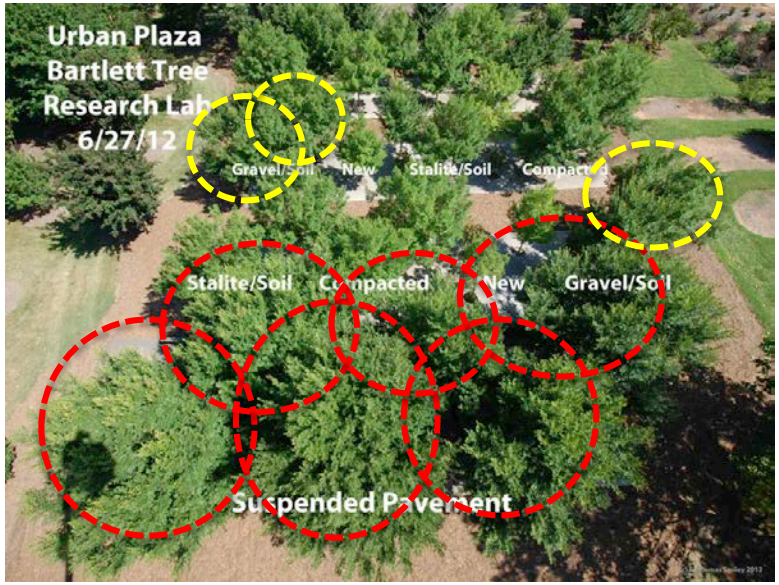
Growing trees in road foundation materials.
Kristoffersen, P. 1999

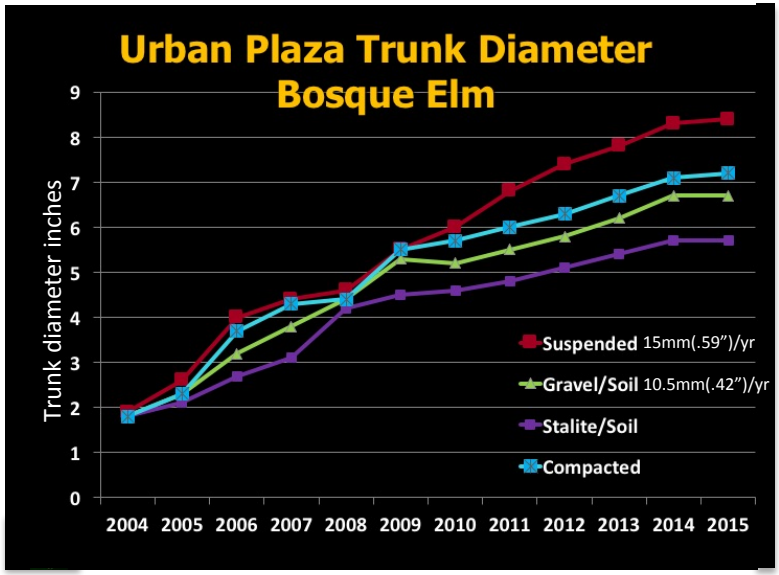
GBSS significantly underperformed when compared to loam soil suspended pavements.

Urban Soil Profiles Boston – 24 trees
Fite, K. 2013

Lindens in Copenhagen were growing at an average DBH increase of 0.95cm (0.37”) per year after 5 years planted in large beds of structural soil.

Structural soil excavations
Buehler, O. 2012





Urban Plaza Suspended Pavement vs GBSS
Smiley, T. 2016

RESEARCH STRUCTURAL SOIL SYSTEMS

Gravel based structural soil GBBS – Stockholm Soil

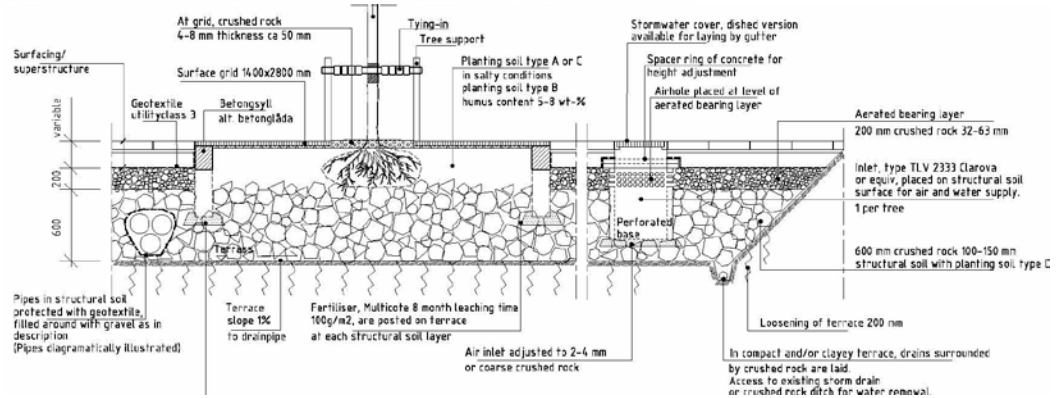
Structural material, 100-150 mm crushed rock, for structural soil. (Photo: Örjan Stål)

(Photo: Örjan Stål)

(Photo: Örjan Stål)

(Photo: Ejörn Embrén)

(Photo: Ejörn Embrén)



Stockholm Soil is approximately Loam 25% soil with **very angular** granite rock combined with many details and specifications that must be closely followed

Planting beds in the city of Stockholm-A handbook Stockholm 2009

RESEARCH STRUCTURAL SOIL SYSTEMS

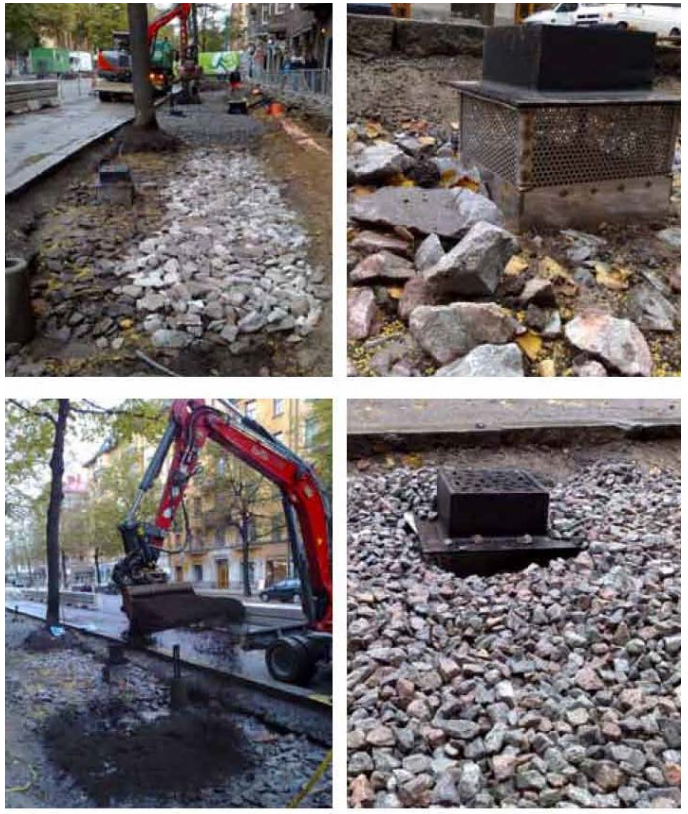
Gravel based structural soil GBBS – Stockholm Soil

Critique of three plantings in built landscapes plus a controlled experiment. Different results for different reasons.

Problems with mixing. Trees growing well in large open soil volumes.

In controlled test plots Trees in structural soil similar to negative control

Structural soil research and examples in Norway
Solfjeld, I. 2014



Creation of structural soil for trees in paved area. The pictures show structural skeleton with aerated bearing layer, an air inlet of type TLV 2333 Clarova with cover, addition of planting soil type D and aerated bearing layer around the air vent. (Photo: Orjan Stål).

481 trees planted in built landscapes.

DBH Increase

Structural soil **with** Storm water	1.18cm (0.46”)/yr
Structural soil **without** Storm water	0.75cm (0.29”)yr
Open soil bed	1.12cm (0.44”)/yr

Stockholm solutions: Experiences of different planting methods
Ostberg, J. 2014

RESEARCH STRUCTURAL SOIL SYSTEMS

Gravel based structural soil GBBS – Stockholm Soil

Stockholm soil method

Slightly smaller stone

2011

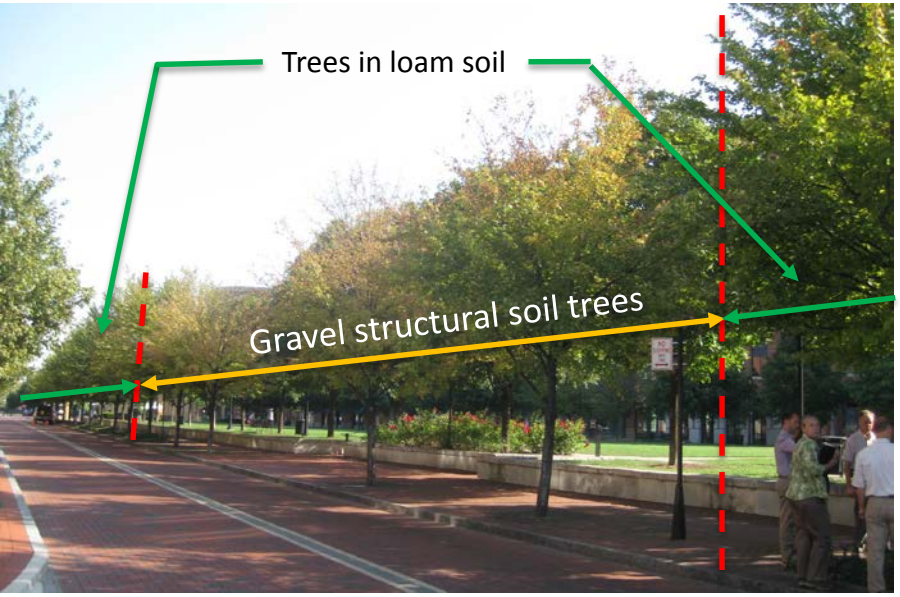
Trees in 2015

Structural Soils for Storm Water.
Wenz, E. 2012

CONCLUSIONS - System effectiveness:

Gravel based structural soil with clay loam soil; the effective amount of soil in the material is between 20 and 25%. Trees can be expected to grow at reasonable rates until the roots fill the available soil space but much more material volume is needed.

More research is needed to determine if the long term soil to tree growth ratio is different for Stockholm soil.



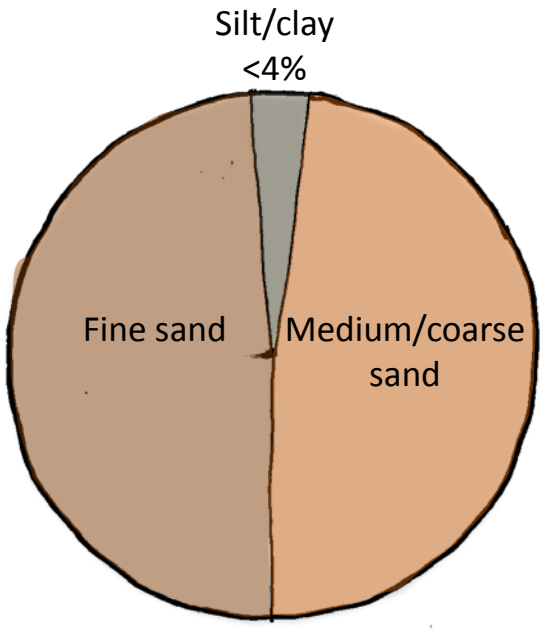
Columbus, OH USA

Stockholm, Sweden
Trees in Stockholm soil

RESEARCH STRUCTURAL SOIL SYSTEMS

Compacted Sand Structural Soil

D60/D10 < 2.5



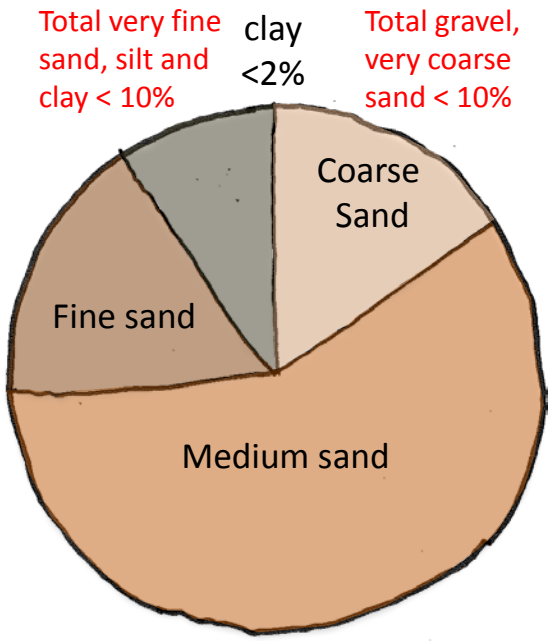
Organic matter
dry weight 4 -(5?) %

Compaction recommendation
70-80% standard proctor

Amsterdam
Tree Soil

Couenberg, E. 1994

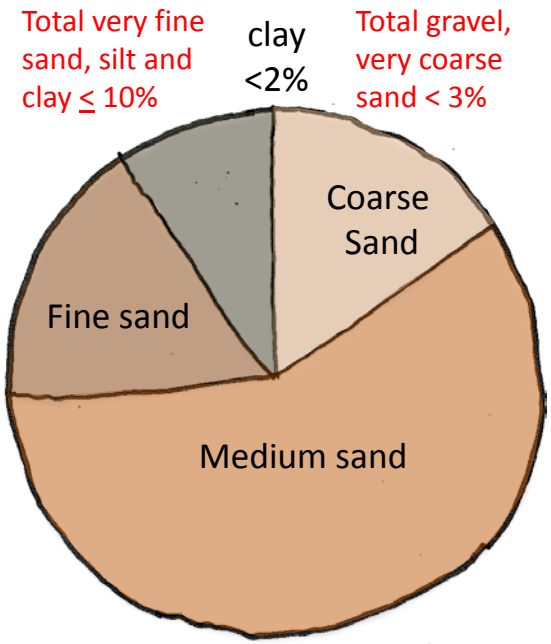
D70/D20 < 3



Organic matter
dry weight 2-3%

Compaction recommendation
95% standard proctor

Sand Based
Structural Soil



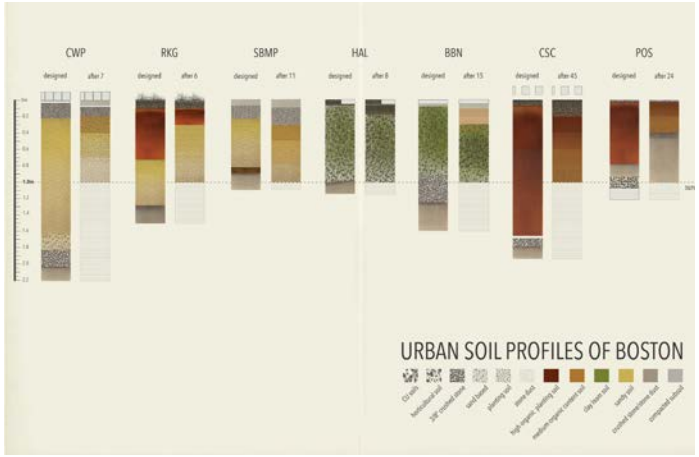
Organic matter Un-defined
but lower is better maybe 2%

No compaction recommendation but
over compaction is a cause of failure.

USGA Greens
Rootzone

RESEARCH STRUCTURAL SOIL SYSTEMS

Compacted Sand Structural Soil

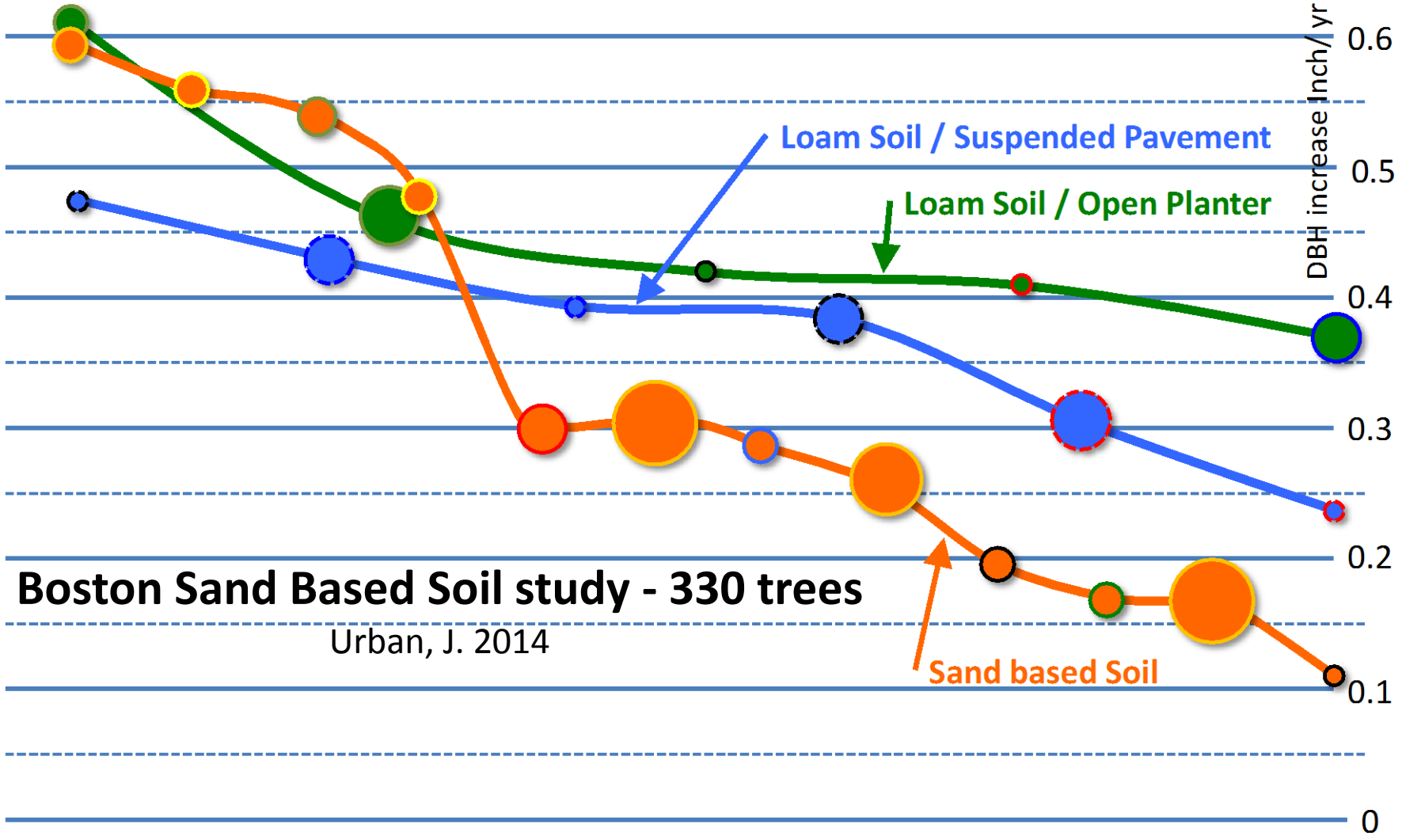


Urban Soil Profiles Boston – 24 trees
Fite, K. 2013

Compacted sand soil and Gravel based soil performed worse that Horticultural soil in open planters **and** suspended pavement.

Growing trees in road foundation materials.
Kristoffersen, P. 1999

Tree growth in Sand Mix similar to “Amsterdam soil” compacted to 80% standard proctor was only about 20% of trees in sandy loam topsoil.



Compacted sand soil generally and significantly underperformed Loam soil in open planters and to a lesser degree loam soil suspended pavement systems.

Higher performing compacted sand soil projects were also projects with higher maintenance.

CONCLUSIONS - System effectiveness:

Compacted sand structural soil is difficult to evaluate for efficiency. Base on current findings, it may be reasonable to rank this option at between 30 to 50% effectiveness compared to loam soil with the further **understanding that trees may never growing as fast or as large** due to limitations other than volume.

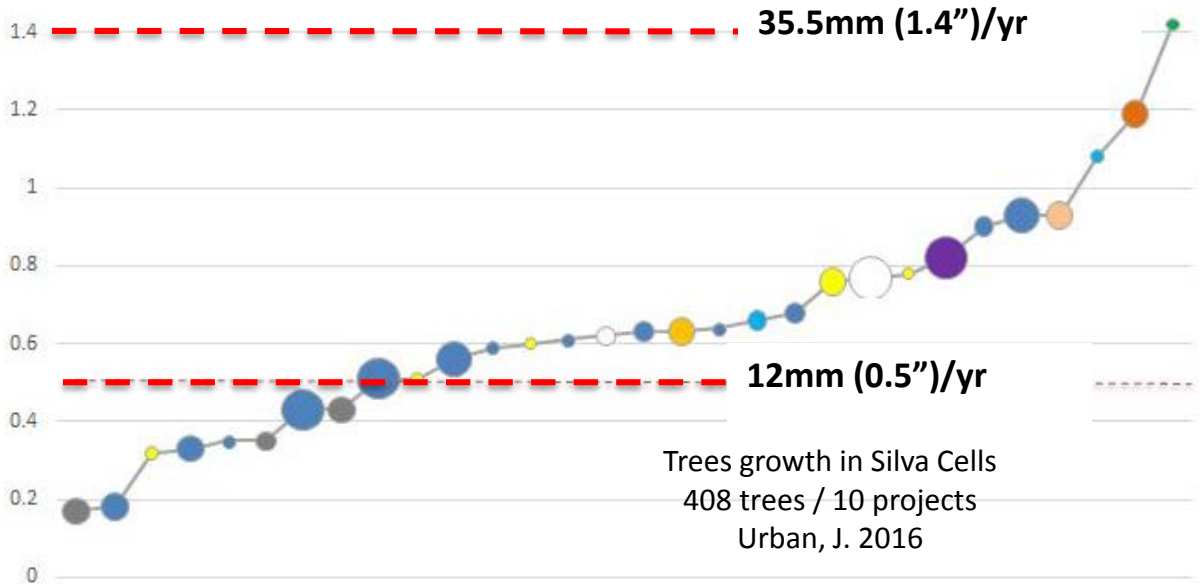
Trees with access to adjacent park soil.

Washington, DC USA
Compacted Sand Structural Soil

Trees with no access to adjacent park soil due to security barrier footing.

2010 2011 **Sugar Beach, Toronto – Silva Cells** 2012 2013

Silva Cells



Trees growth in Silva Cells
408 trees / 10 projects
Urban, J. 2016

RESEARCH
Comparative research all approaches

Treatments: Six replicate trees for each treatment

- 1. Gravel Base Structural Soil (GBSS)
- 2. Compacted Sand Structural Soil (CSSS)
- 3. StrataCell (unscreened loam soil)
- 4. Silva Cell (unscreened loam soil)
- 5. Compacted Control (unscreened loam soil)
- 6. Non-compacted/open planter Control (unscreened loam soil)

Each Plot is 1524mm(5’) x 1524mm(5’) x 609mm(2’) deep, with gravel (57) and a drain pipe below.

All plots were lined with a medium weight Fiberweb Geotextile.

Trees: Liriodendron chinense

Installed late summer 2014
Date collected October 2016 and October 2017
Final data and destructive root observations October 2017

Soil under pavement plots, Bartlett Labs, Charlotte, NC USA
Urban, J. 2012 and Smiley, T.

RESEARCH

Comparative research all approaches

Soil under pavement plots, Bartlett Labs, Charlotte, NC USA
Urban, J. 2012 and Smiley, T.

Gravel Based Structural Soil (GBSS)

80% gravel (#57), 20% soil.
Bubbler irrigation at tree.
Compacted to 95% Proctor.

Compacted Sand Structural Soil (CSSS)

Gravel layer below/ above sand.
Drip ring and bubbler irrigation.
Compacted to 95% Proctor

Stratacell CityGreen

Unscreened sandy loam soil.
Bubbler irrigation at tree.
Vibration compaction top only.

Silva Cells DeepRoot

Unscreened sandy loam soil.
Bubbler irrigation at tree.
Walk thru compaction to about 75% proctor.

RESEARCH

Comparative research all approaches

Treatment	Non-compacted Soil volume (cubic yards)
Strata cell	2.1 a
Silva cell	2.5 b
Control -Non compacted	2.7 c
Sand BSS	3.3 d
Gravel BSS	3.3 d
Control -Compacted	3.3 d
Space available	*1.6*

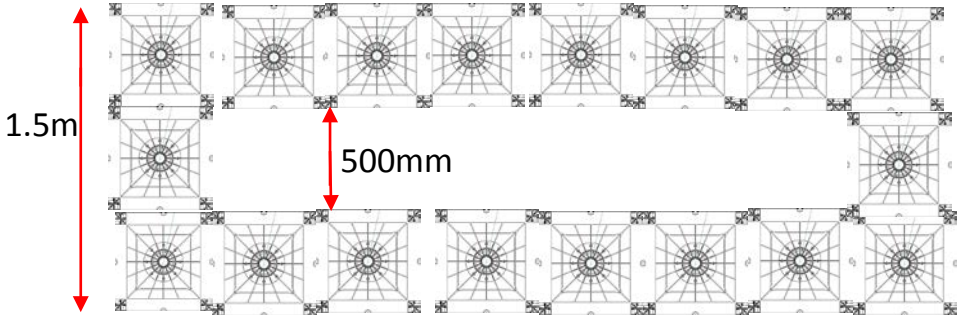
Silva Cells Strata Cells

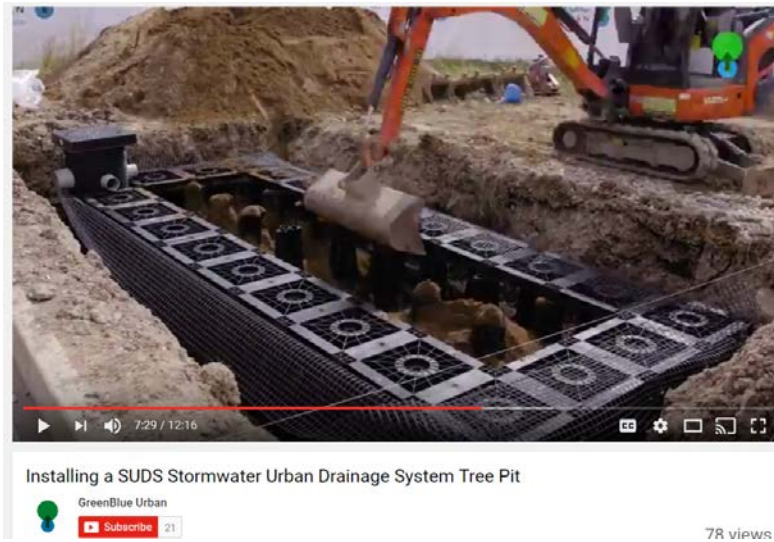
Soil under pavement plots, Bartlett Labs, Charlotte, NC USA
Urban, J. 2012 and Smiley, T.

Root Space - Not included in the Bartelett study

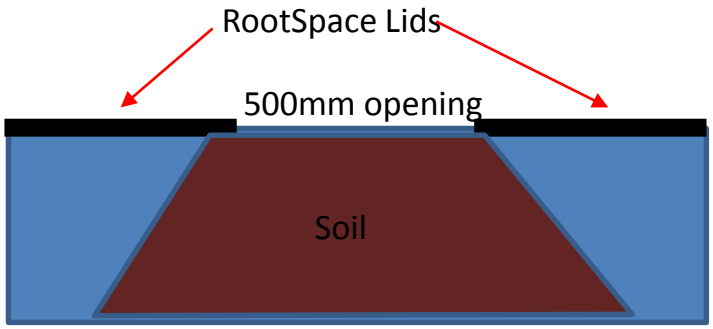
RootSpace Caps need to be installed around the perimeter before soil is installed

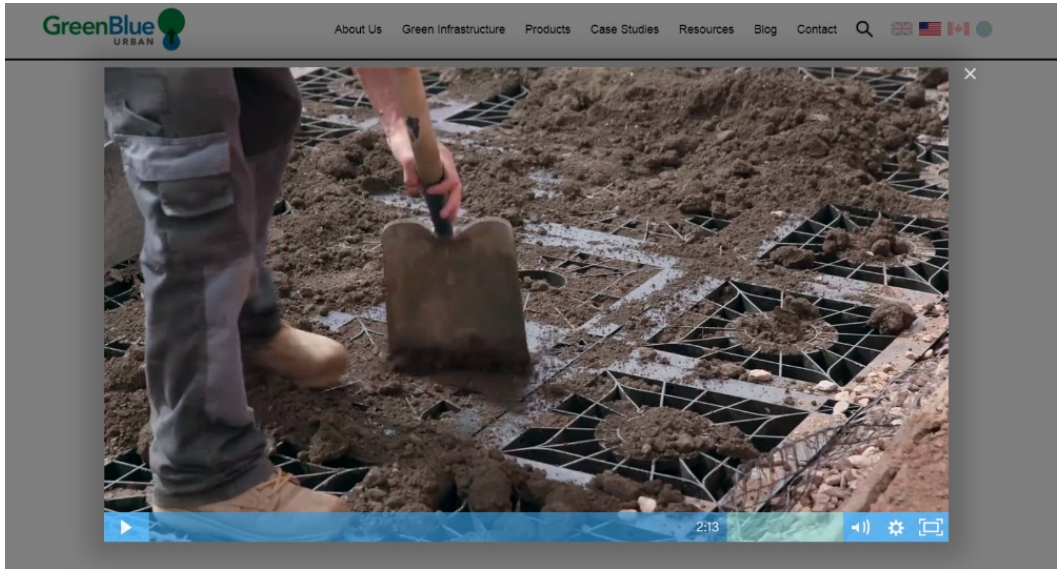
For this 1.5m wide RootSpace configuration soil can only be Loaded into the 500mm opening.





This will result in the perimeter RootSpace units not being fully filled.
There is no ability to provide walk through compaction in the perimeter RootSpace units.
This will also result in significant soil settlement.





Silva Cells

Sand Soil

Low compacted loam control

Silva Cells

Strata Cells

CONCLUSIONS - System effectiveness: **Suspended pavement systems** that are filled with **unscreened loam soils** are the most effective at growing trees and are **equivalent to loam soil** provided that the volume of the structural elements holding up the sidewalk are subtracted from the overall volume of the installation.

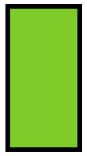
Gravel
structural soil

Sand soil

Bartlett Soil Under Pavement Study
2017 Results

LOAM SOIL

1000 c.f.
28.3m3



100% EFFICIENT

Post Soil Cells

30.3m3

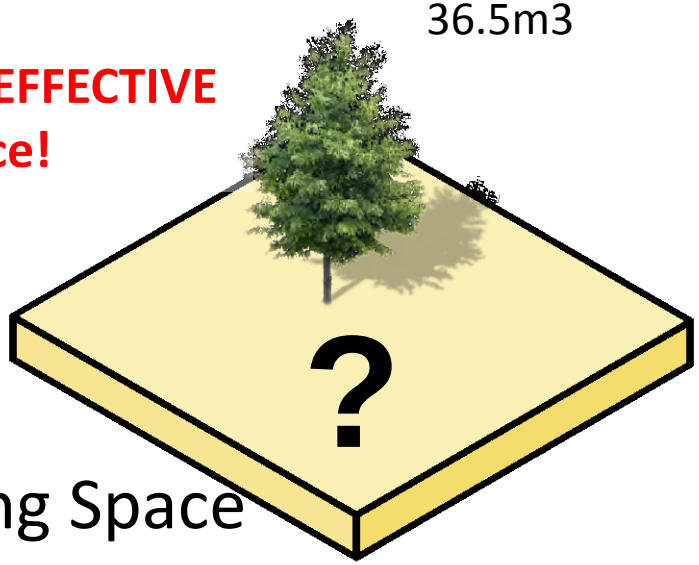
93% EFFICIENT

Segmented Soil Cells

1290 c.f.
36.5m3

71% EFFICIENT

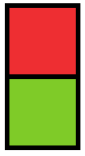
Calculating EFFECTIVE rooting space!



Effective Rooting Space

COMPACTED SAND SOIL

2000 c.f.
56.6m3



50% EFFICIENT

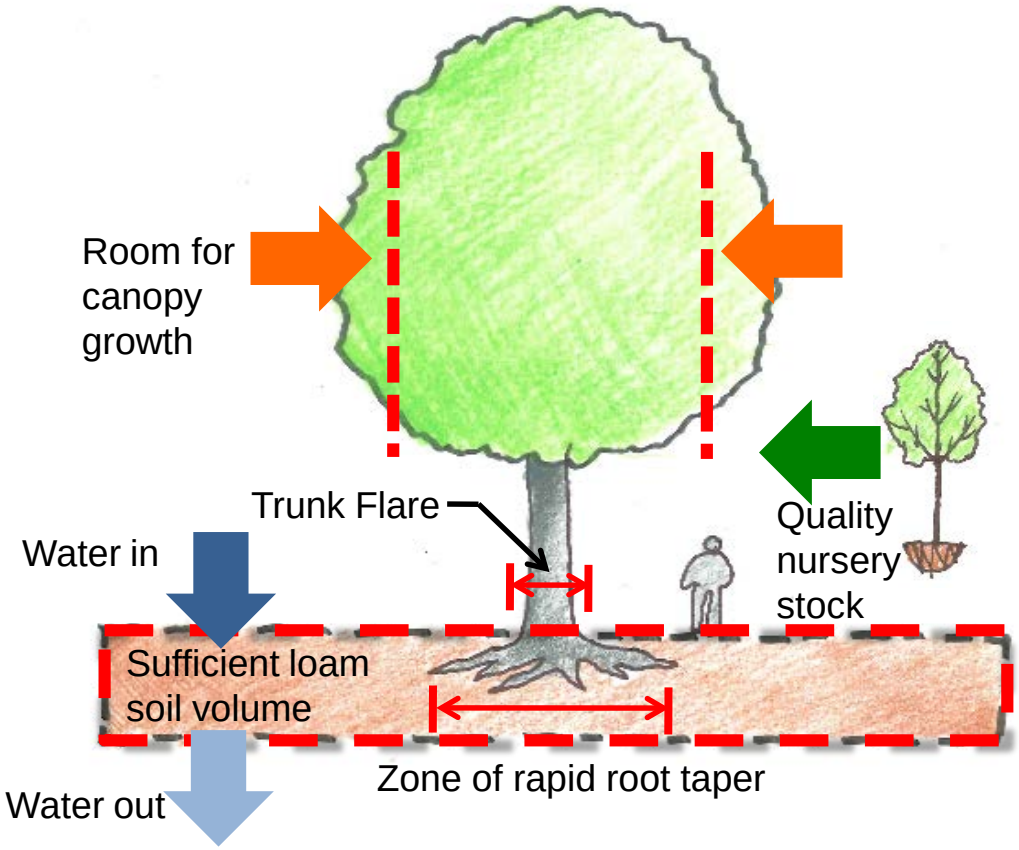
GRAVEL BASED STRUCTURAL SOIL

5000 c.f.
141.6m3

20% EFFICIENT

Recommendation - Design improvements

Designers must pay more attention to all the parts of the tree in pavement problem. The choice of a soil approach is only one small part of a very complex design problem.



Including the soils beyond area of improvement

TREE AND SOIL RESEARCH FUND FOR LANDSCAPE ARCHITECTURE
'TRSF'

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Designate donation for the TSRF

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More Research Needed!

ASLA Tree and Soil Research Blog
https://treeandsoilresearch.asla.org

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