

Irrigation and Drainage Engineering

(Soil Water Regime Management)

(ENV-549, A.Y. 2025-26)

4ETCS, Master option

Prof. Paolo Perona

Platform of Hydraulic Constructions

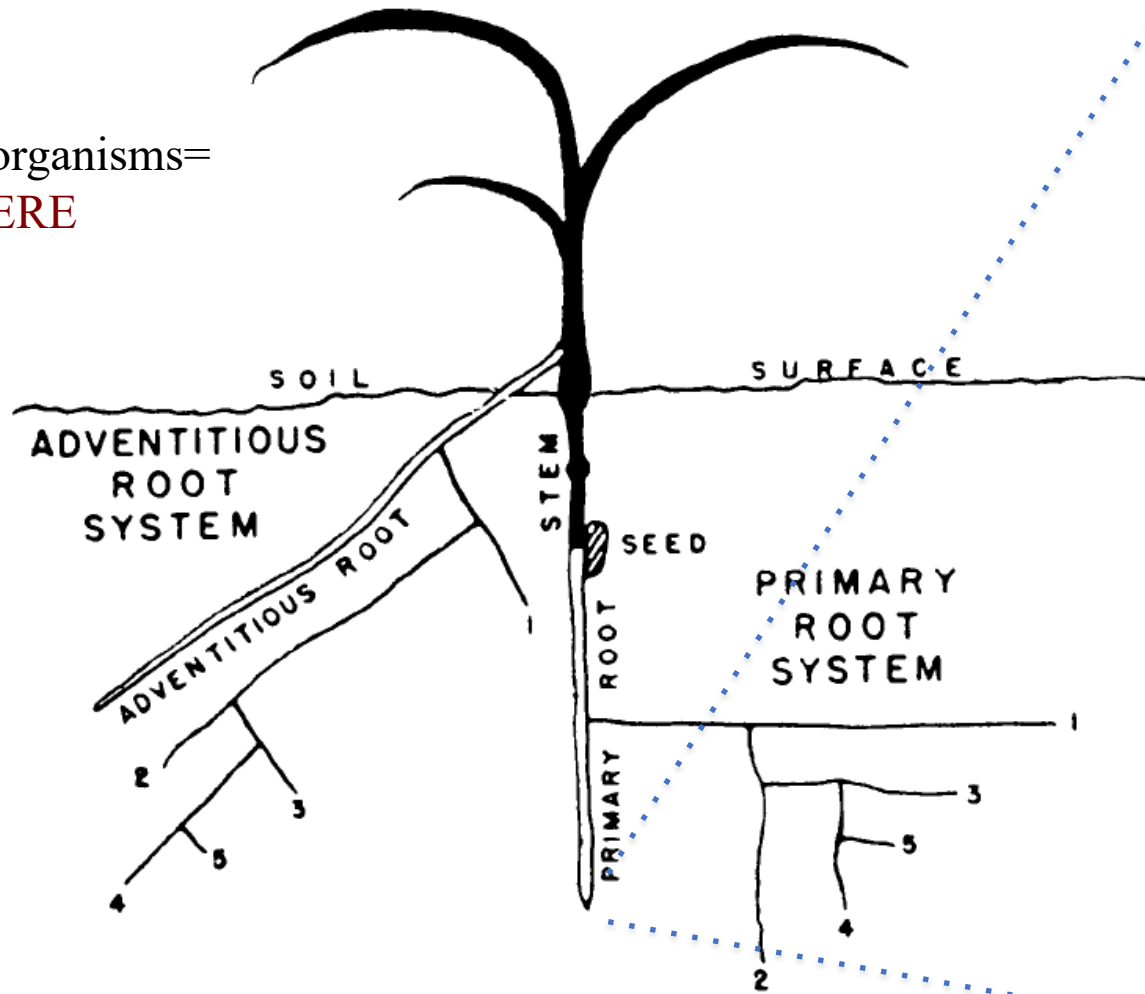


Lecture 1-2: Plant root
structure, functions and
tropism

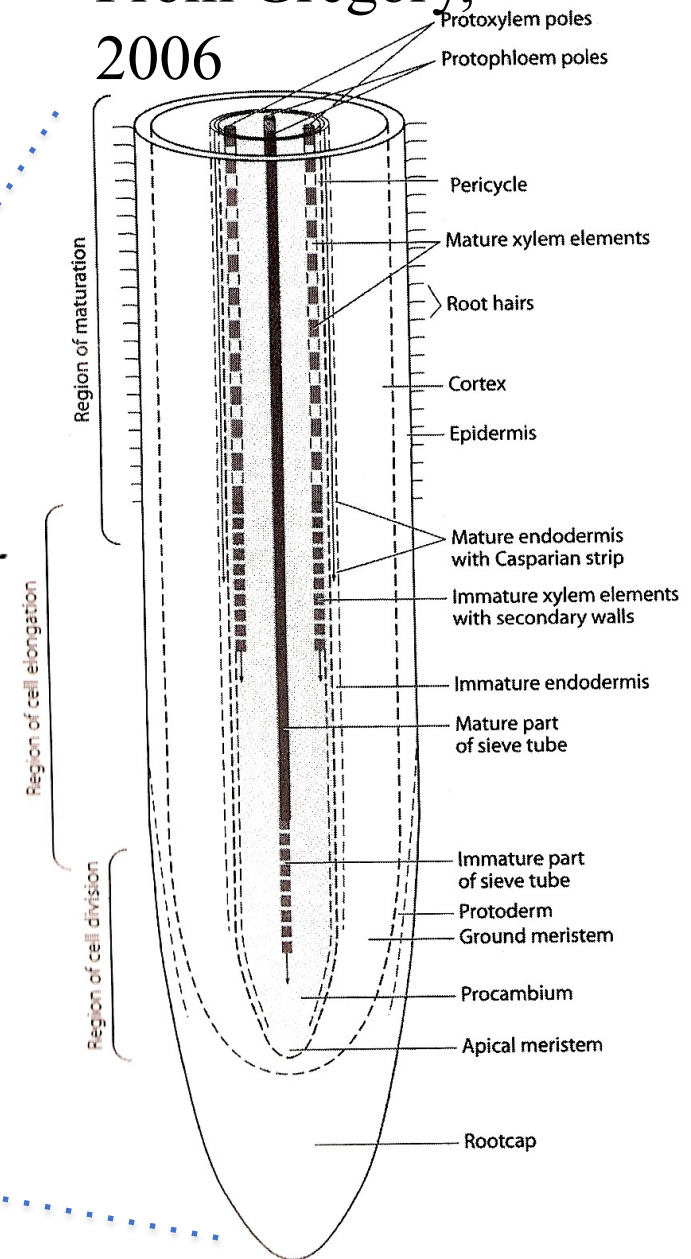
An essay on the structure and functional roles of the root apparatus

Root architecture

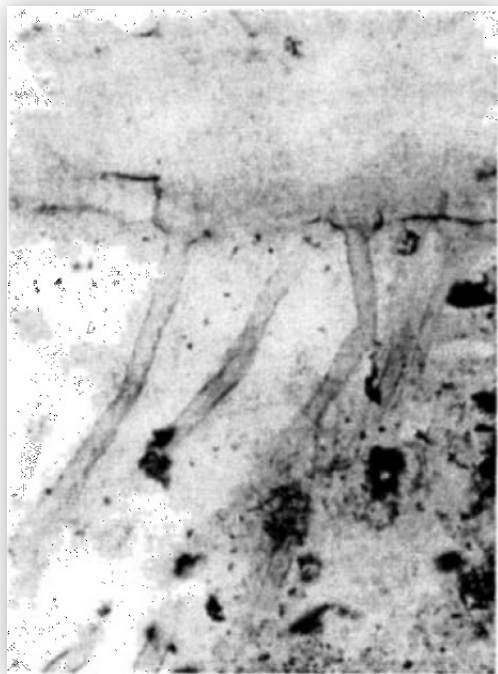
Roots+soil+organisms=
RHIZOSPHERE



From Gregory,
2006



Early roots



Ancient root systems: (Left) The oldest (396 Mio ys) rooting structure preserved in growth position; (Right) A 377 Mio-ys-old root of *Chamaendendron multisporangiatum* showing multiple bifurcations on both the root (R) and the Stem (S).

Source: Waisel et al., Plant Roots: the hidden half

Leonardo Da Vinci (1498): Radice, detail from wall painting (fresco), Sala delle Asse, Castello Sforzesco, Milano

Paleozoic landscapes shaped by plant evolution

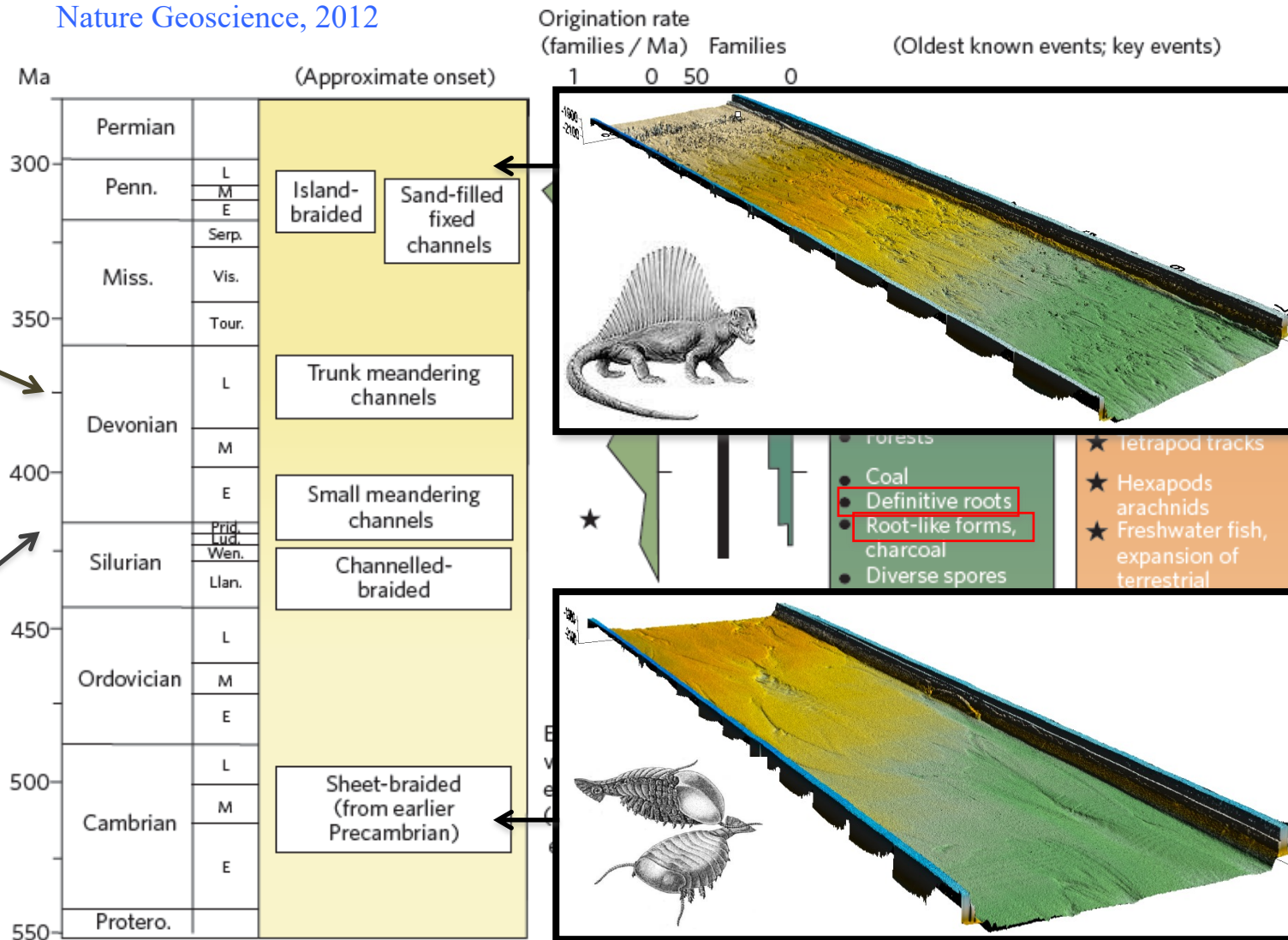
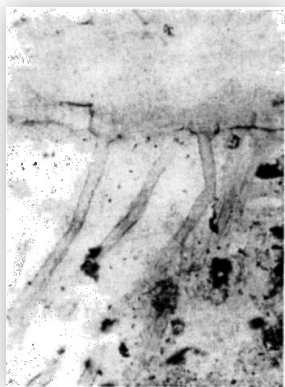
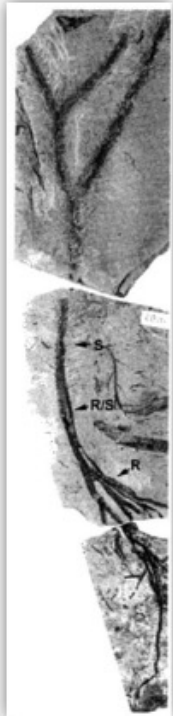
Fluvial style

Plant evolution

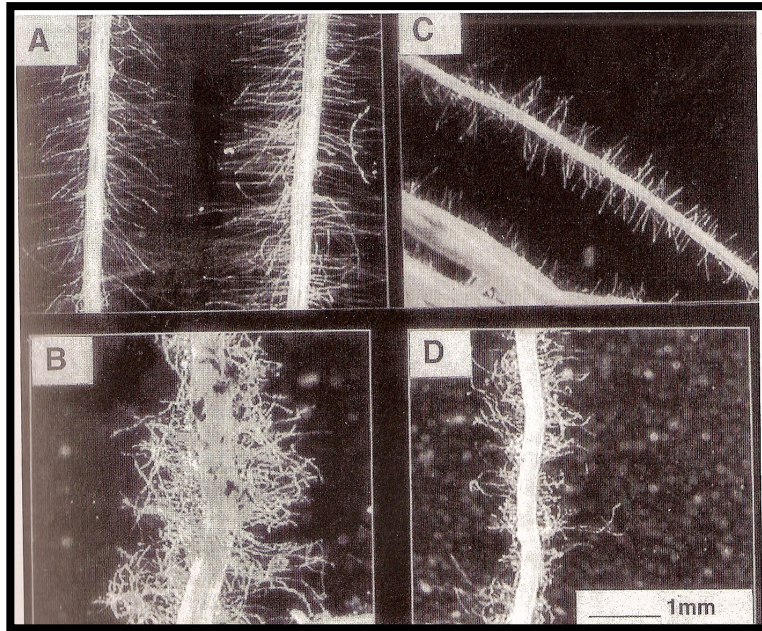
Animal evolution

After Gibling and Davies,
Nature Geoscience, 2012

Chamaendron multisporangiatum



Root hairs



Edmaier, Perona et al.
HESS, 2011

Xerophyte: plant requiring very little water

Mesophyte: plant requiring only moderate amount of water

Hydrophyte: plant growing only in or on water

Halophyte: plant adapted to grow in saline conditions

Phreatophyte: plant obtaining water from near the water table



Root hairs are commonly observed

Root architecture systems

PRIMARY ROOT SYSTEMS

Type I (Mesophytic): Primary root is fibrous fleshy and long. Secondary roots also long.

Type II (Mesophytic) : Primary root is fibrous and short. Secondary roots are long and well branched

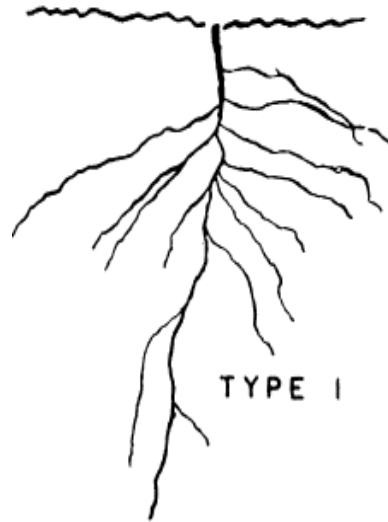
Type III (Xerophytic): Primary root is long and fibrous. Secondary roots short and regularly spread

Type IV (Xerophytic and Mesophytic): Primary root long and tender, secondary are long if close to the surface

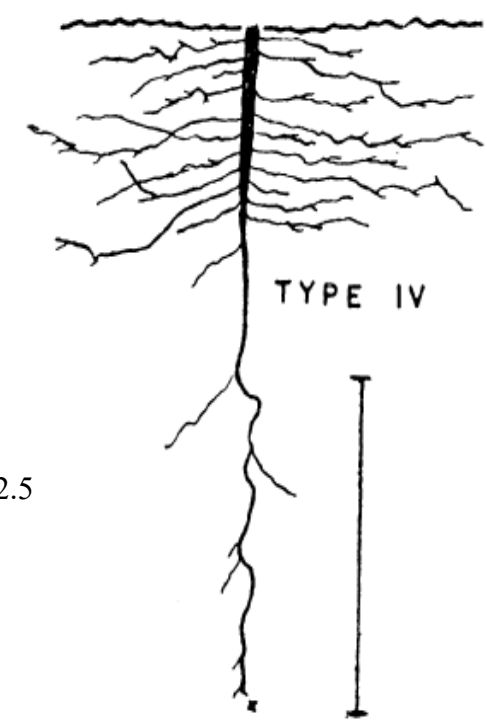
Type V (Xerophytic): Primary root is forked and with only first order lateral roots

Type VI (Xerophytic): Primary root as type V, secondary roots as type IV

Amsinchia spectabilis, scale 1:1



Ratibida columnaris, scale 1:2



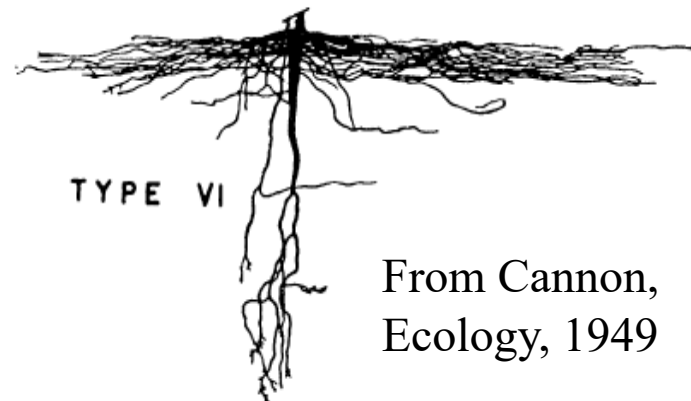
Disoda papposa, scale 1:2.5



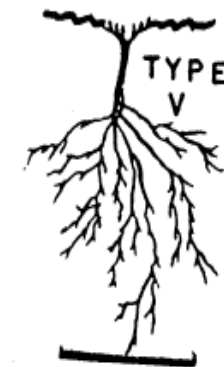
Castanea Tungurutt, scale 1:400



Altingia excelsa, scale 1:400



Eritchium argenteum, scale 1:10



From Cannon,
Ecology, 1949

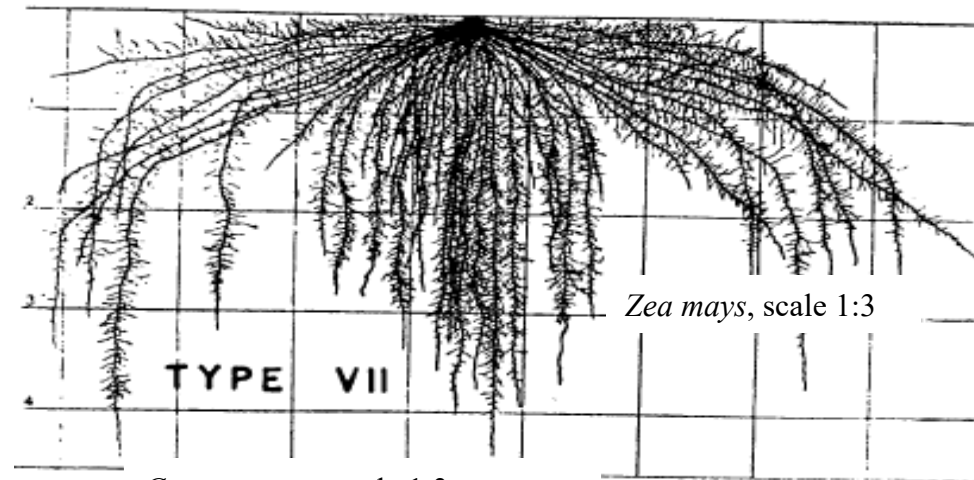
Adventitious root systems

Type VII (Mesophytic and hydrophytic): Group adventitious roots on short horiz or vertic shoot axis

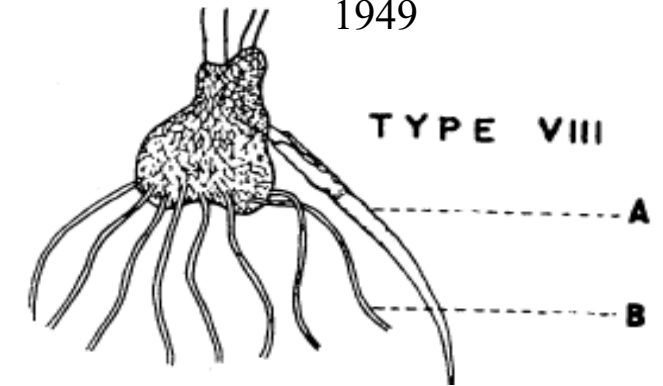
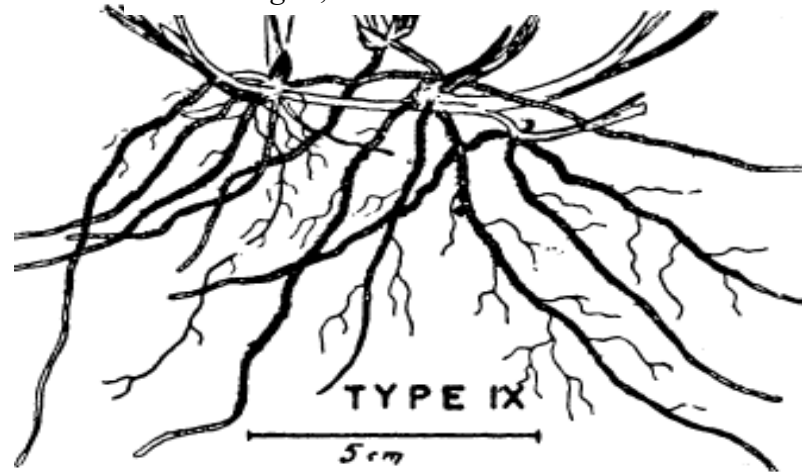
Type VIII (Mesophytic): Centralized multiformal root system with contractile (A) and absorbing-anchoring (B) roots

Type IX (Hydrophytic): adventitious roots form in the aerial portion of the shoot, are fibrous or fleshy

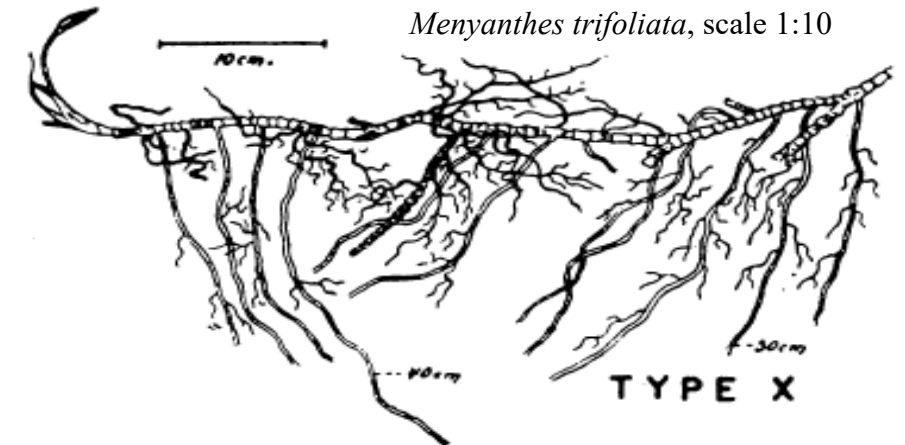
Type X (Mesophytic and hydrophytic): Adventitious are more than one kind and more than one group:



Carex irrigua, scale 1:3

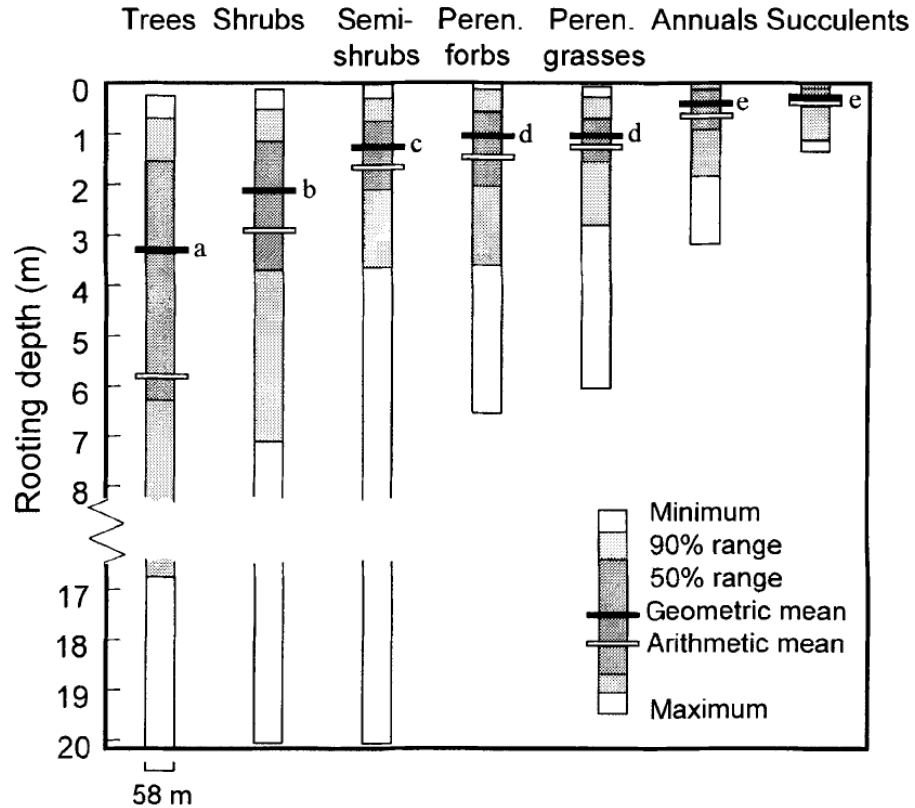


Brodiaea lactea, scale 1:4



Menyanthes trifoliata, scale 1:10

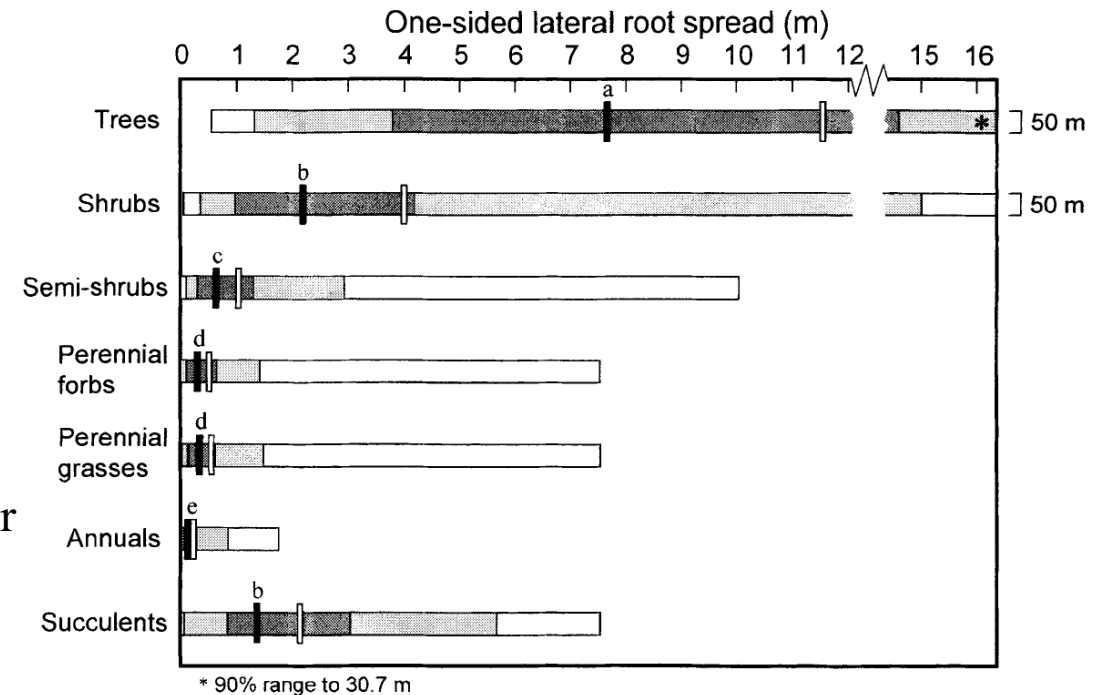
Example root statistics



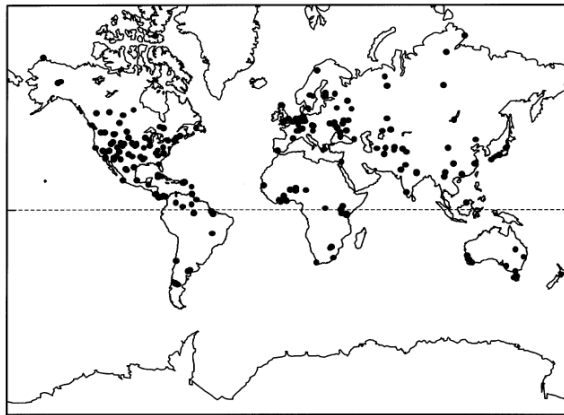
After Schenk and Jackson, J of Ecology, 2002

Classification of rooting depth statistics for plants growing in water limited ecosystems

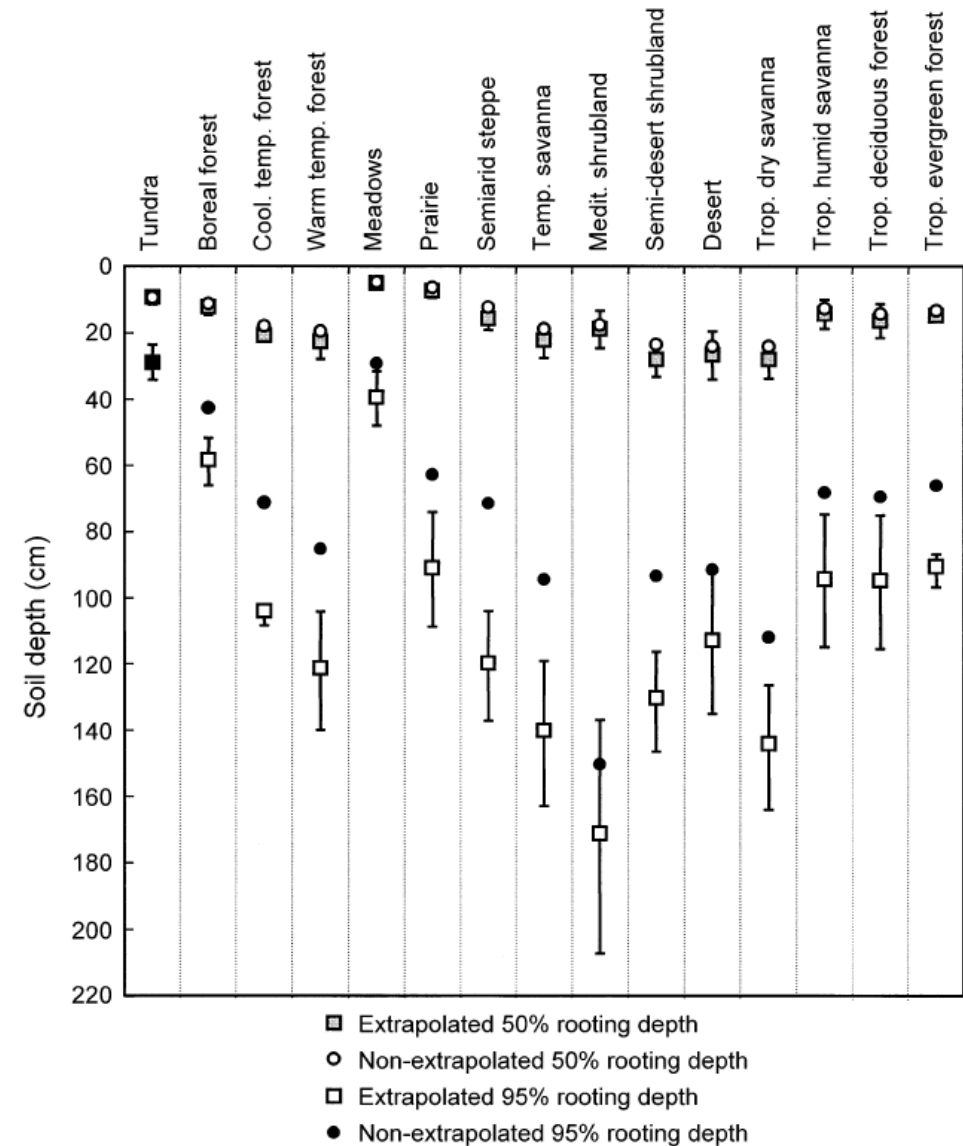
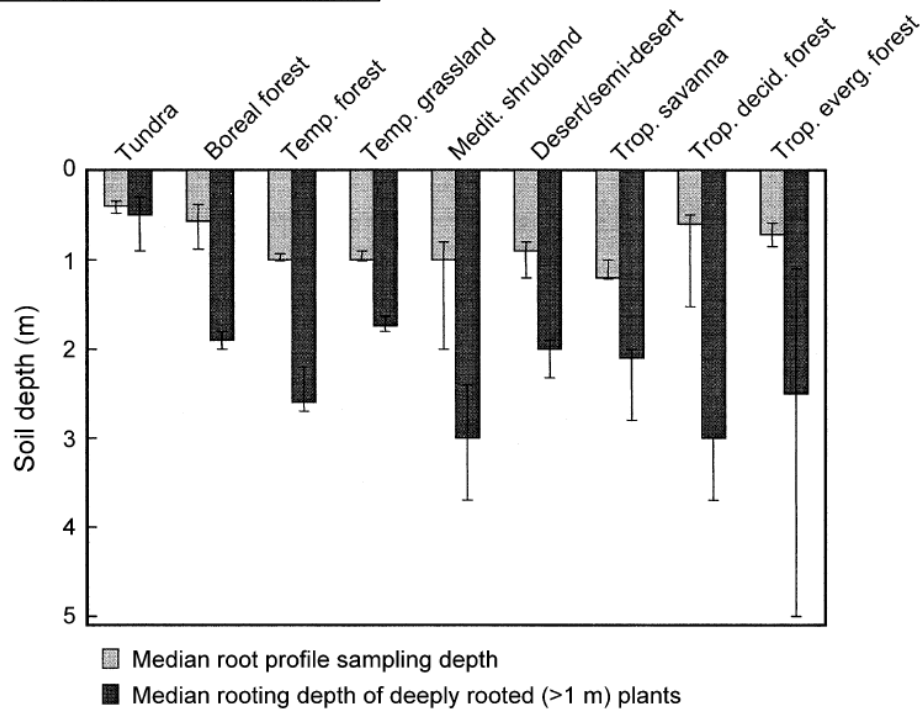
Classification of lateral root spread statistics for plants growing in water limited ecosystems



Biogeography of roots

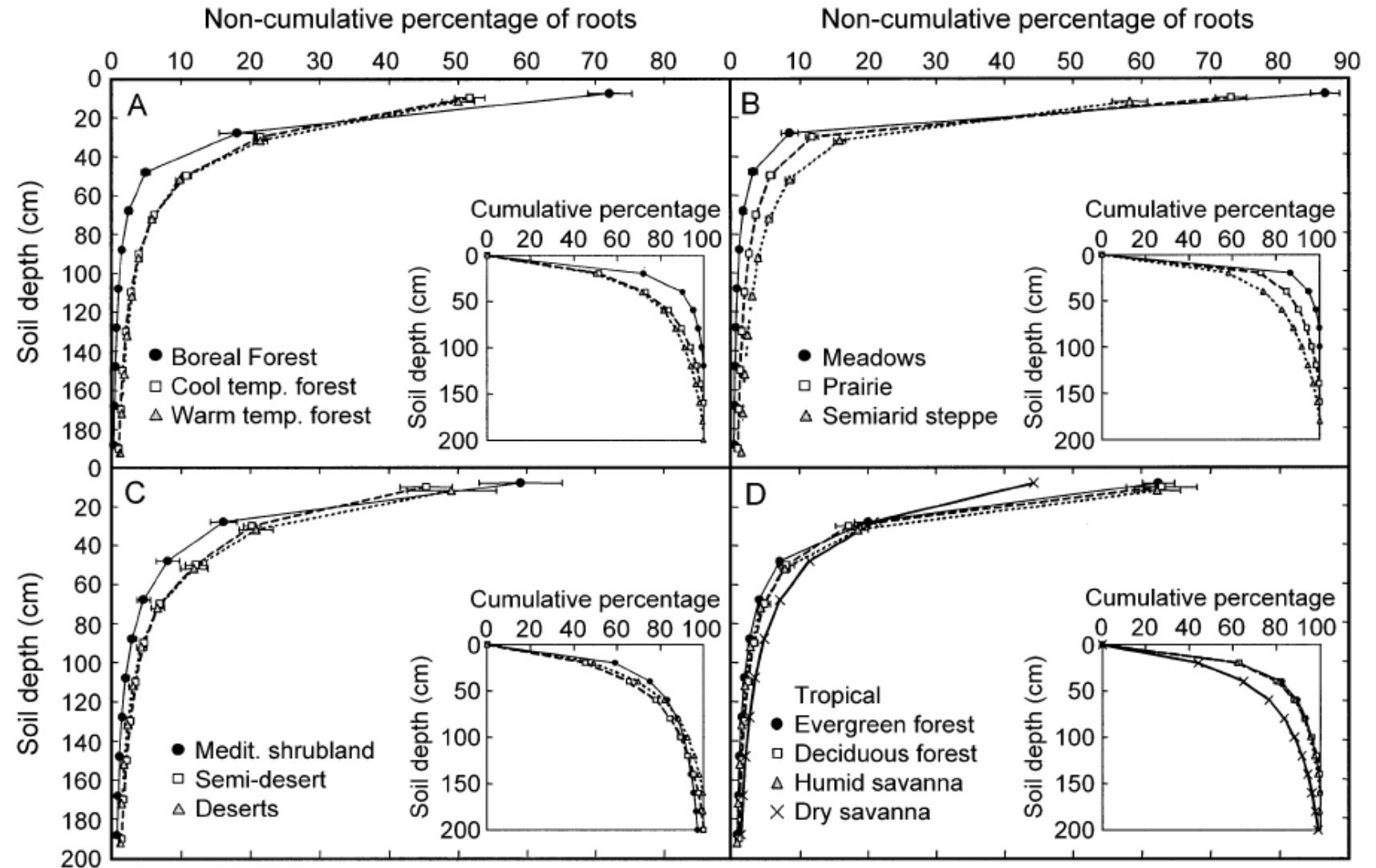


After Shenk and Jackson, Ecol. Monogr., 2002



Vertical root distribution

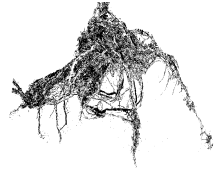
Data from precipitation-driven environments (After Shenk and Jackson, Ecol Monogr., 2002)



Root growth of some crop plants

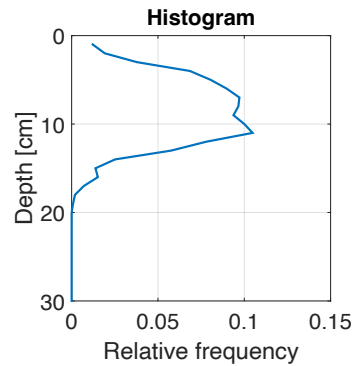
Cabbage

Edited black and white image



Surface root area: 82.6 cm²

Day 60

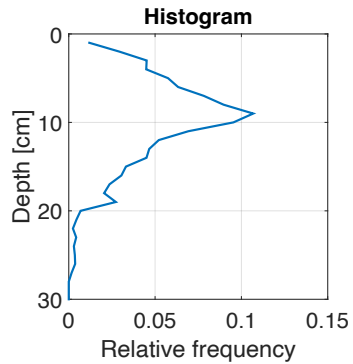


Edited black and white image



Surface root area: 183.1 cm²

Day 90



Notice, how crop plants tend to have a mode of the root profile which is not located at the topsoil!

In order to understand why we need to first learn about roots' "tropism"

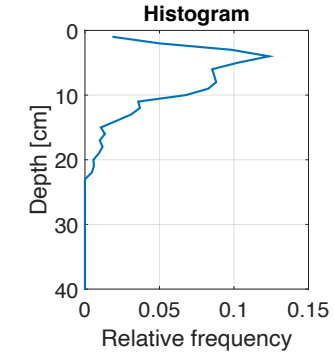
Eggplant

Edited black and white image



Surface root area: 23.3 cm²

Day 30

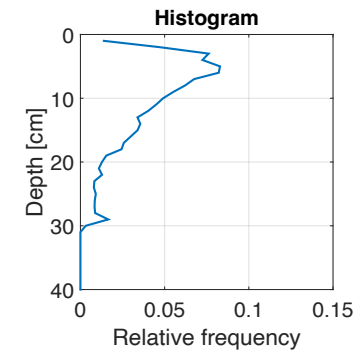


Edited black and white image



Surface root area: 92.5 cm²

Day 55

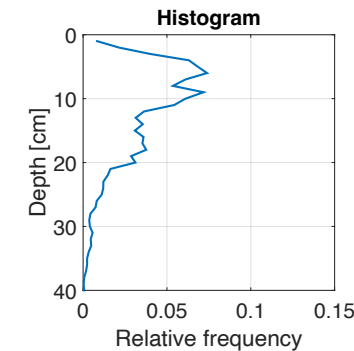


Edited black and white image



Surface root area: 89.4 cm²

Day 75



Müller, T. 2014;
Müller et al.,
Agric. Water
Manag., 2016

Plant roots tropism

“Tropism” is the response of biological systems to environmental stimuli

- Gravitropism (Geotropism): root response to gravity (Knight, 1811)
- Hydrotropism: response to soil moisture gradients (Sachs 1872)
- Phototropism: response to light sources (Darwin, 1881*)
- Thigmotropism: response to mechanical impedance (Darwin, 1881)
- Oxytropism (aerotropism): response to oxygen concentration (Pfeffer, 1906)
- Chemotropism: response to nutrients (chemicals) concentration
- Plagiotropism: response to temperature gradients (Kaspar and bland 1992)

Darwin and Darwin, The power of movement in plants, 1881

Pea root growth



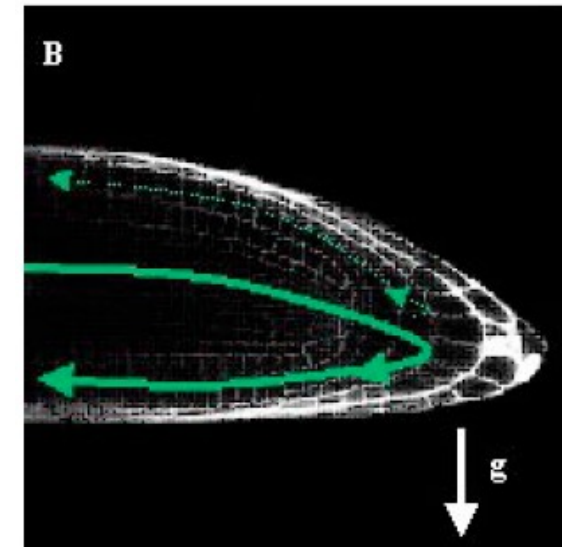
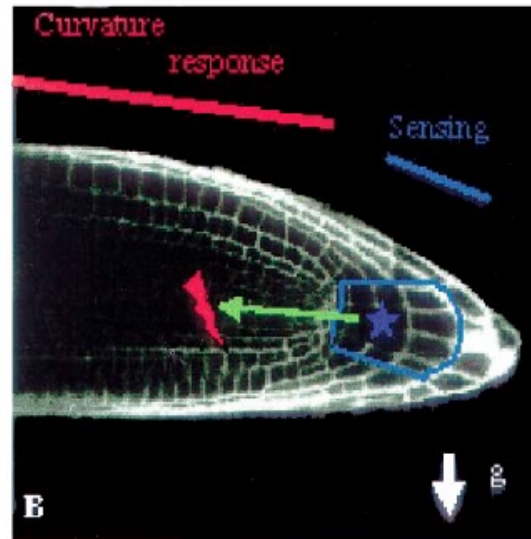
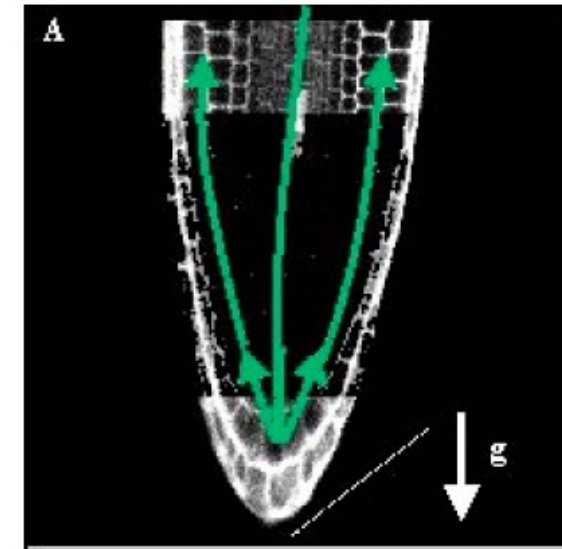
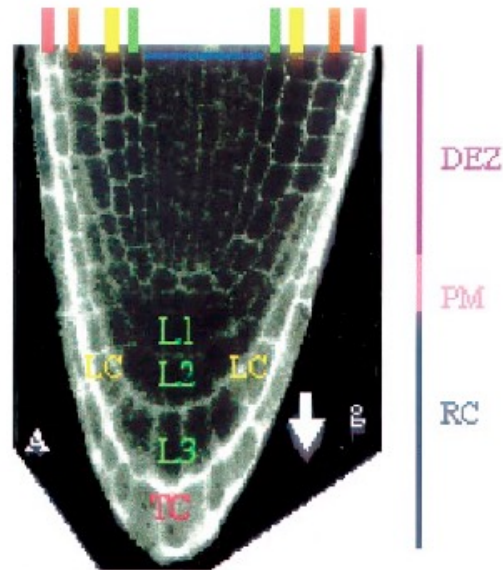
Example: gravitropism

After Boonsirichai et al.,
Ann. Rev. Plant Biol.,
2002

Root cap cells are like gravity sensors

Mechanism (Fountain model): hormonal fluxes (Auxin) and sedimentation of starch-filled amyloplast within statocytes (cells of root cap)

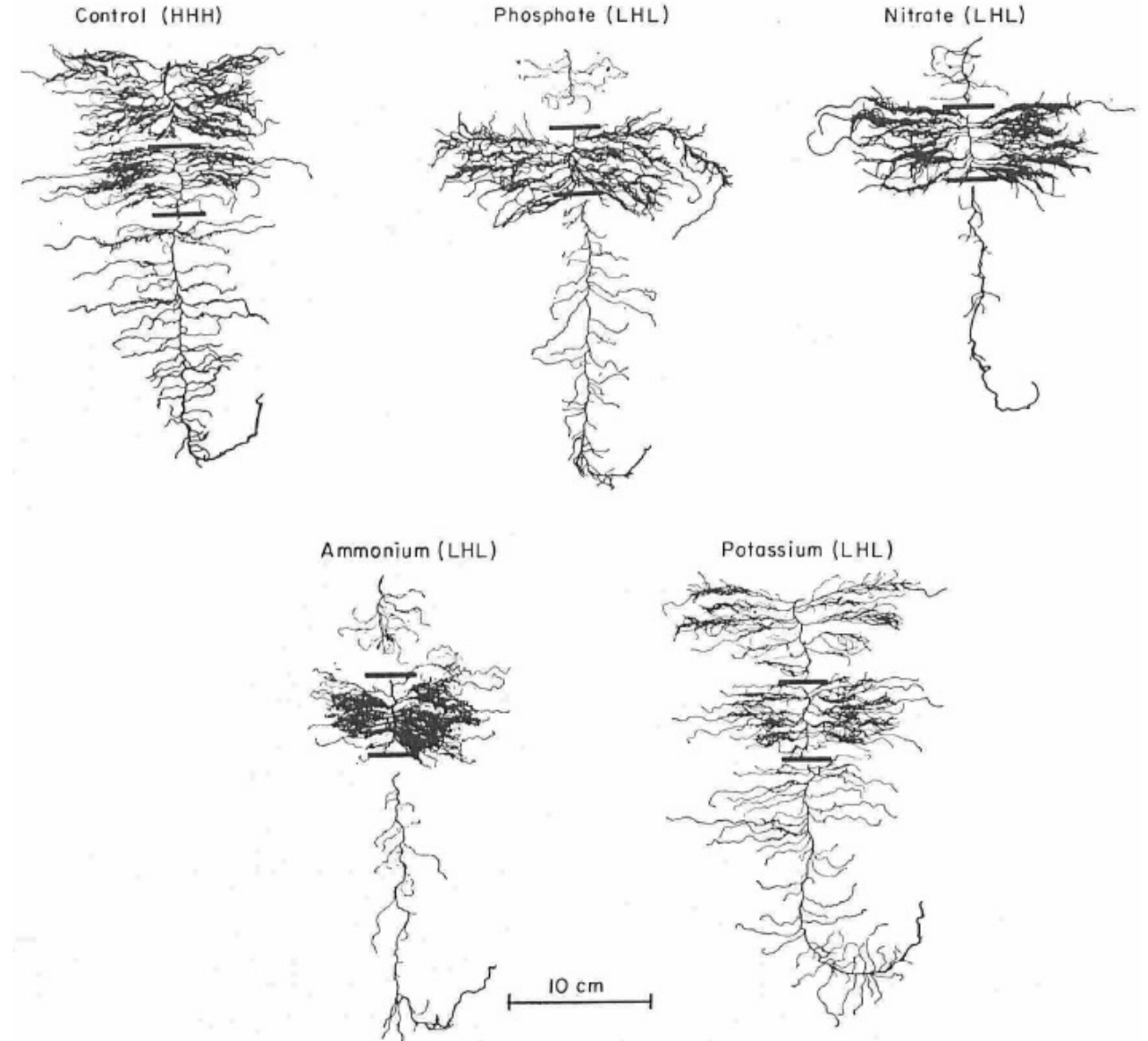
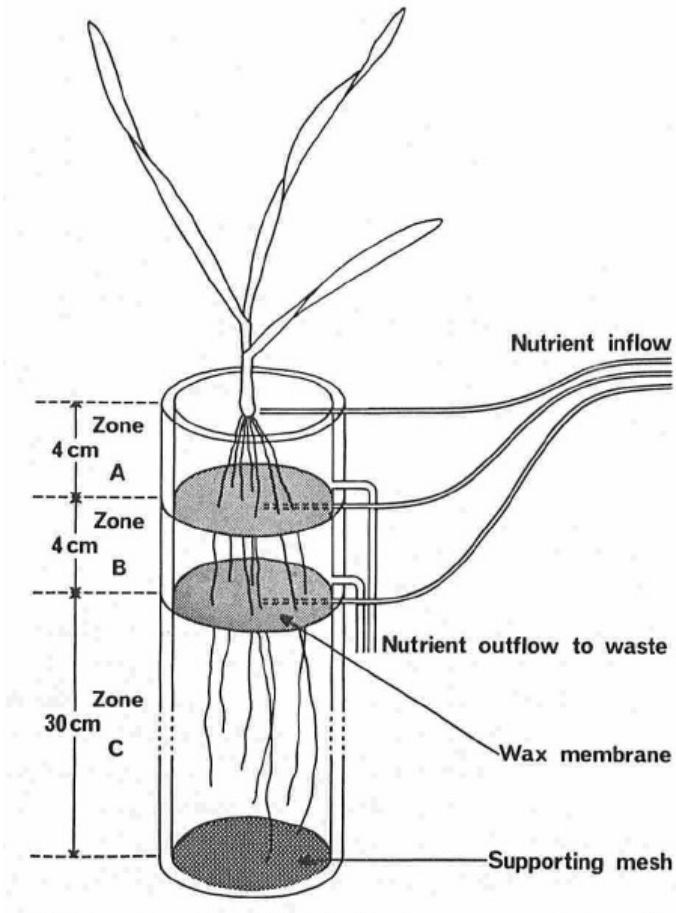
See also Aloni et al., Annals of Botany, 2006



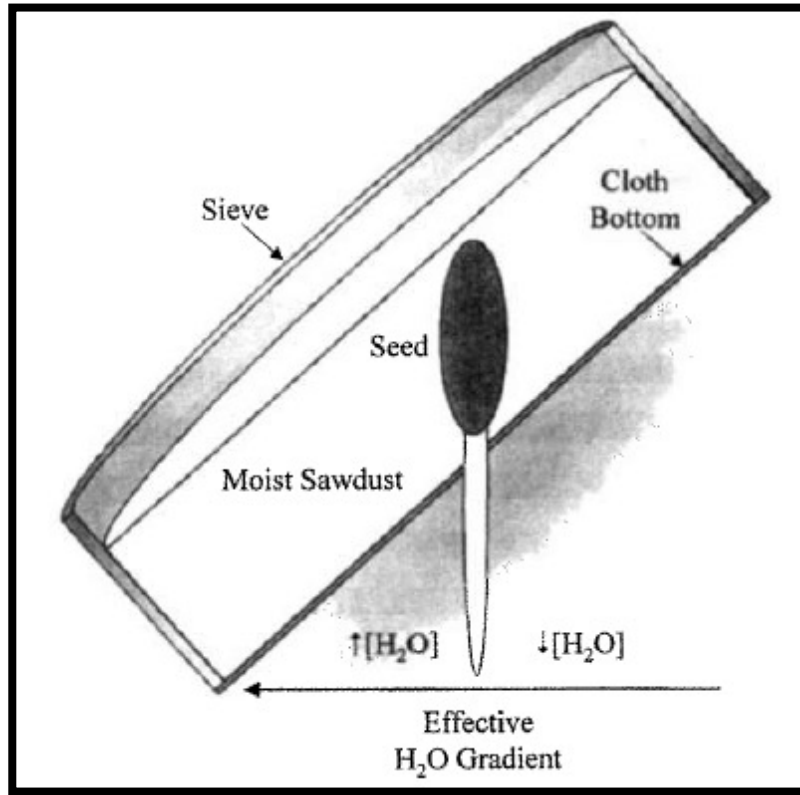
Example: chemotropism

After Drew, New Phyt., 1975

Barley plants grown for 21 days in controlled environment

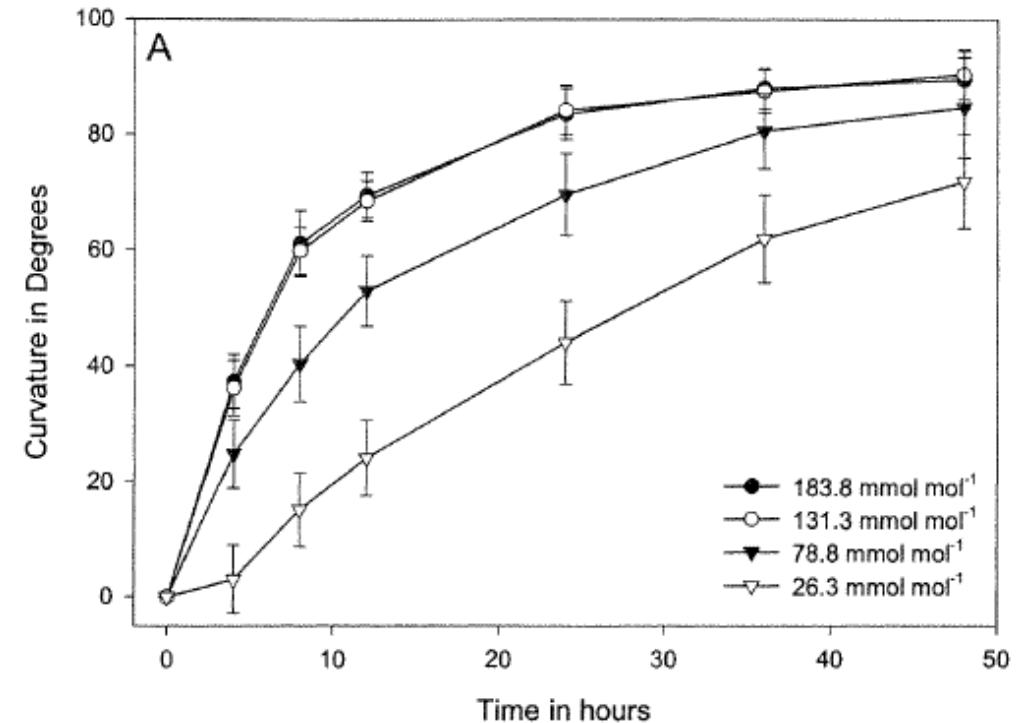


Example: hydrotropism and oxitropism



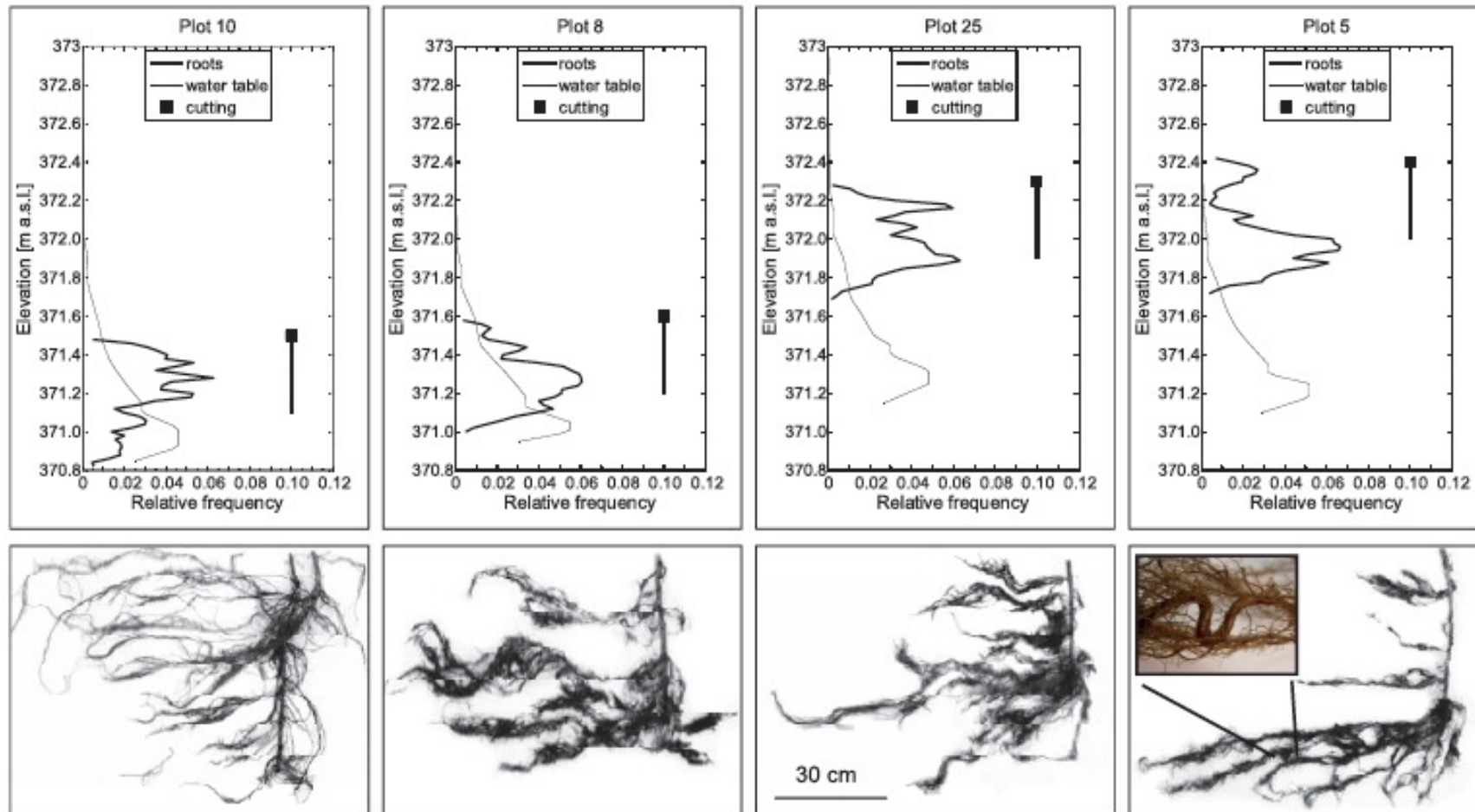
Sachs' experiment (1872) to demonstrate hydrotropism

Question: do tropism responses control the vertical density distribution? In which environments?



Porterfield and Musgrave, 1998. Roots curvature change and growth proceeds toward region with higher O₂ concentration

Hydrotropism vs oxitropism

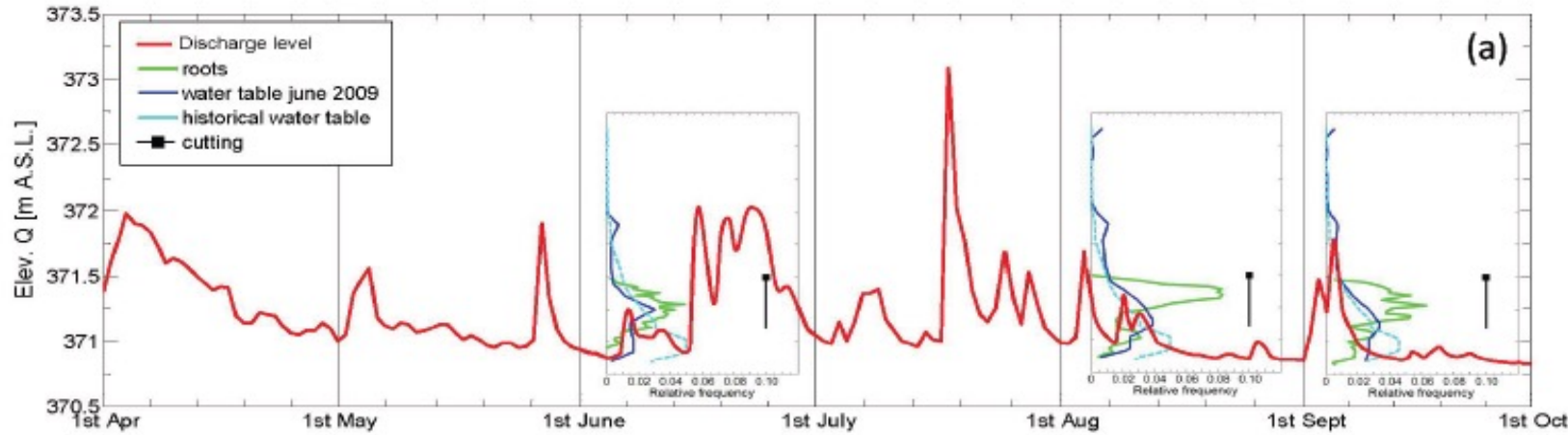


After
Pasquale et
al., Ecol. Eng.
2012

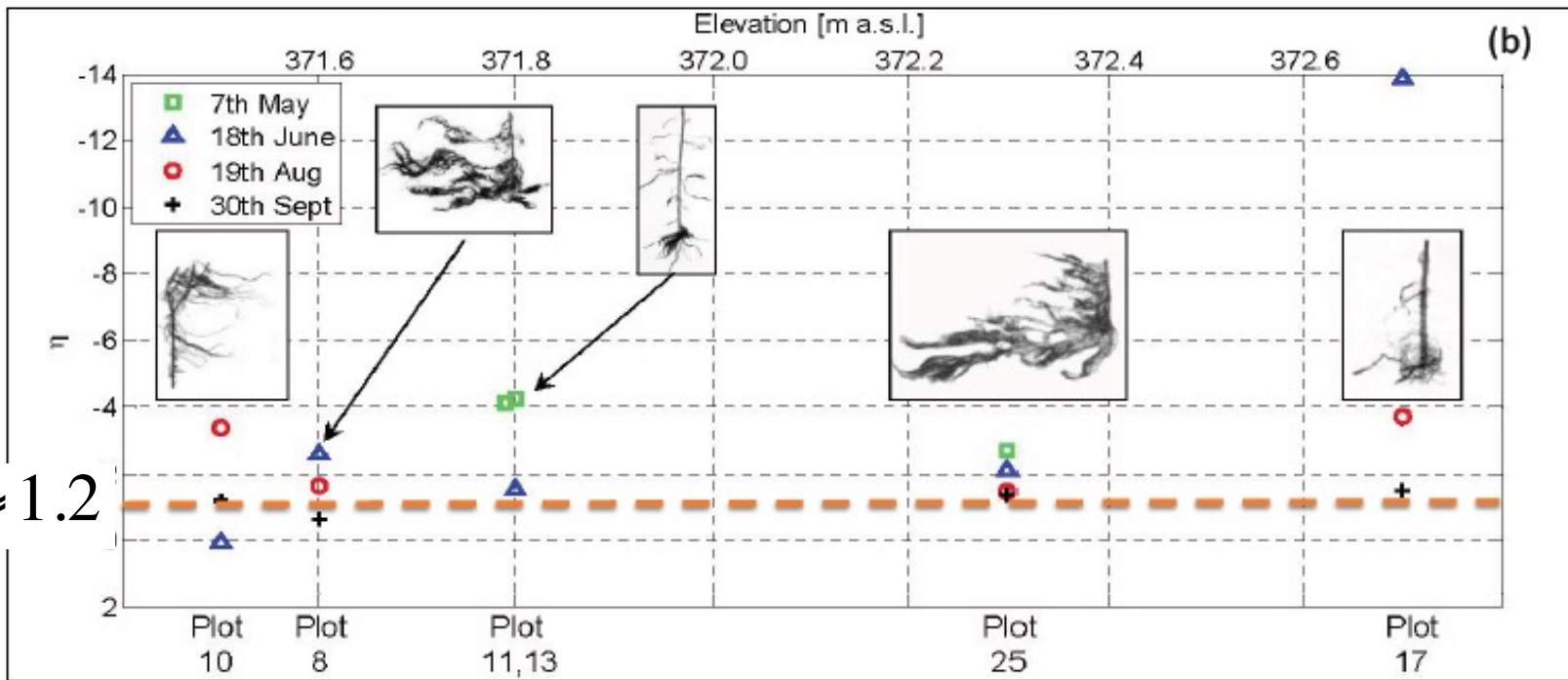
Assumptions (confirmed):

- Nutrient availability is not a limiting factor for plants to grow (verified from soil samples)
- Precipitation is uniformly distributed at the island scale

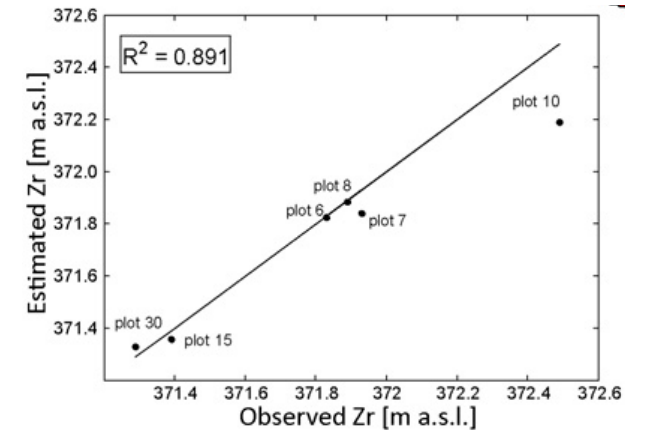
Dimensionless scaling



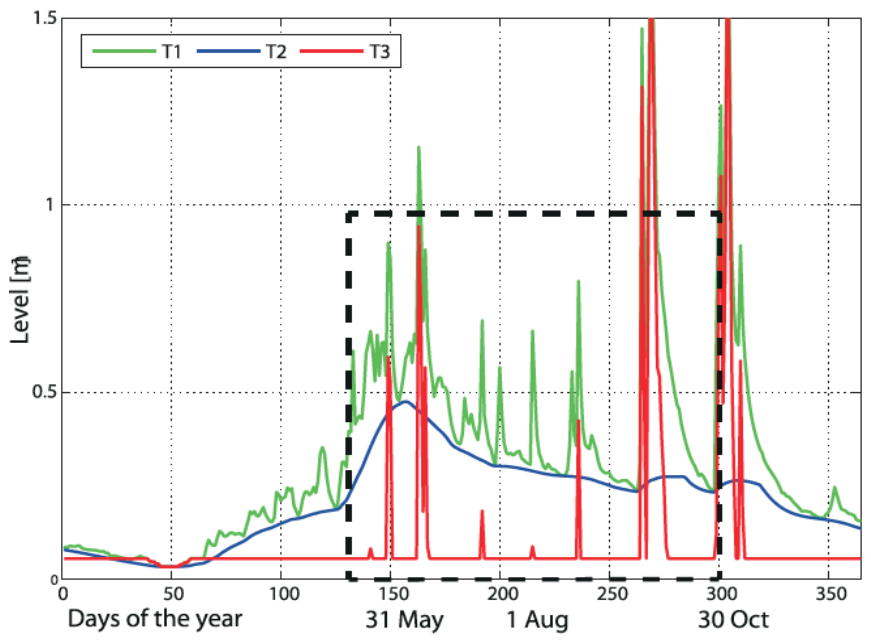
After Pasquale et al., Ecol. Eng. 2012



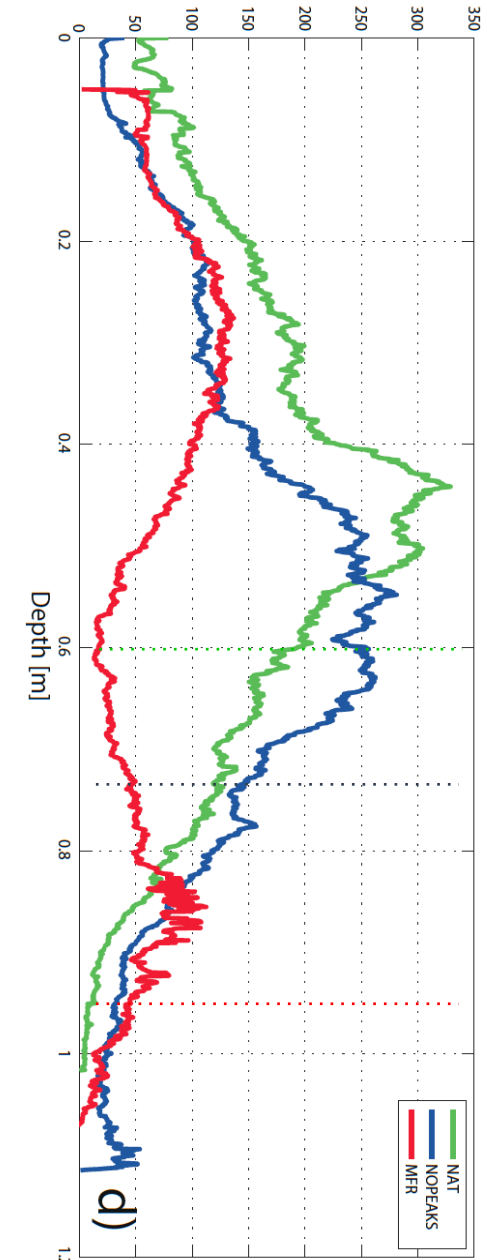
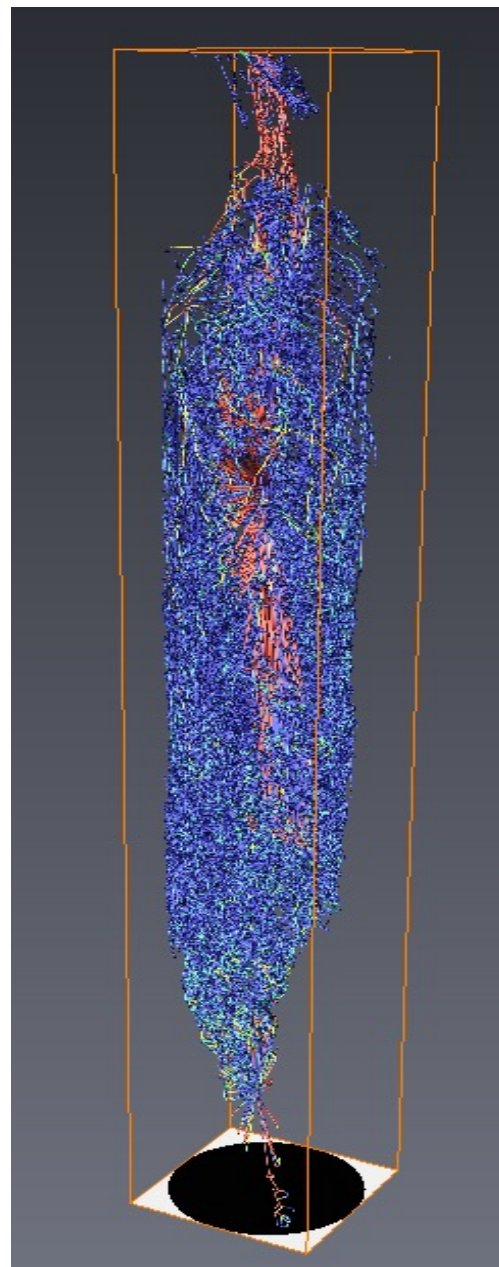
Inter-seasons prediction



Response to changing water regime

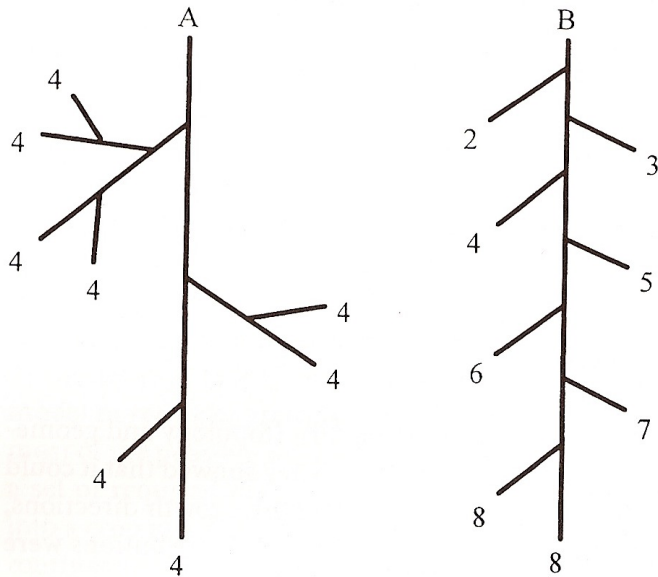
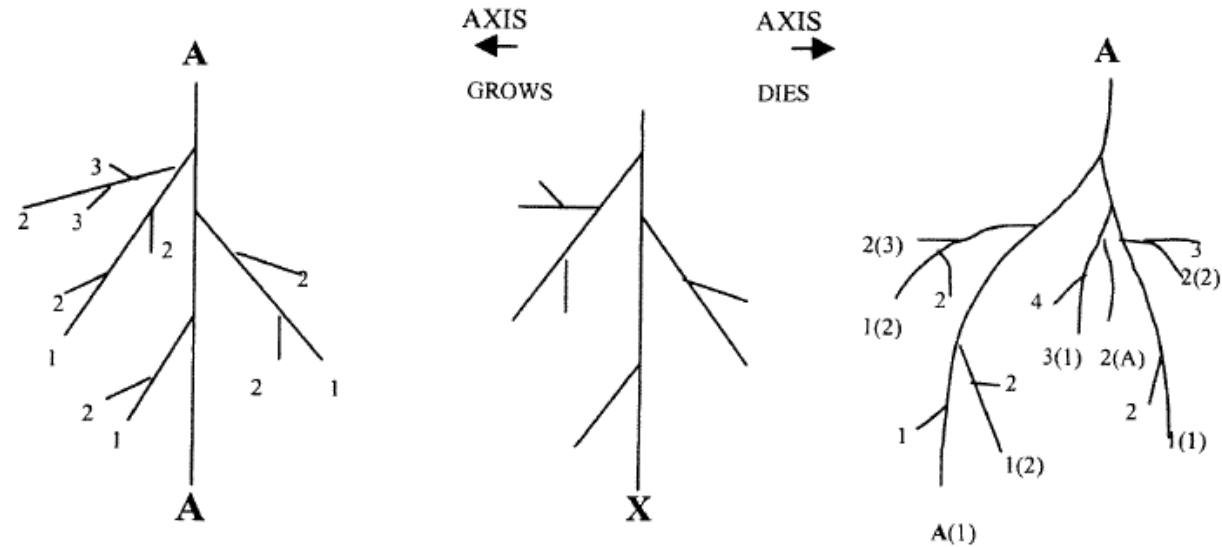


Gorla et al.,
WRR, 2015



Explicit root architecture models

An unsuited classification based on the number of links. These can change the order as roots grow.

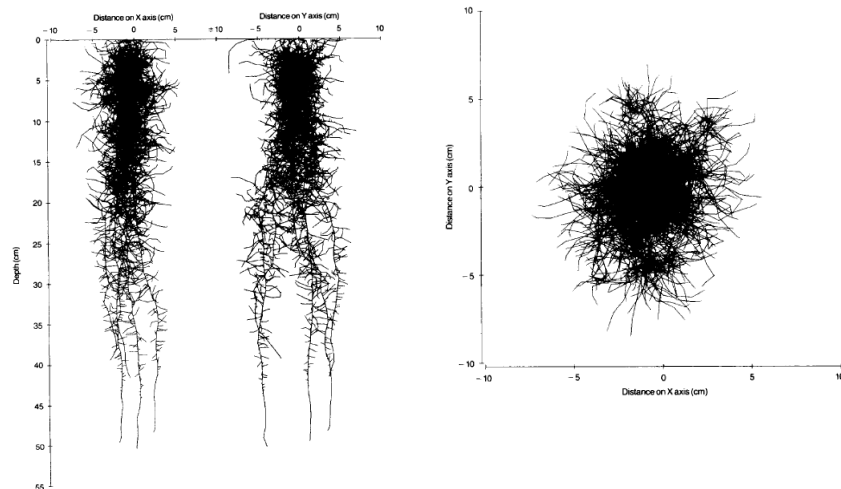


Scheme of two major root architectures topologies: (A) dichotomous; (B) herringbone (from Smit, 2000). Numerals are exterior path length, the number of links in the path from each exterior link to the base link

See also: Fitter, *New Phytologist*, 1987;
Bernston, *New Phytologist*, 1997

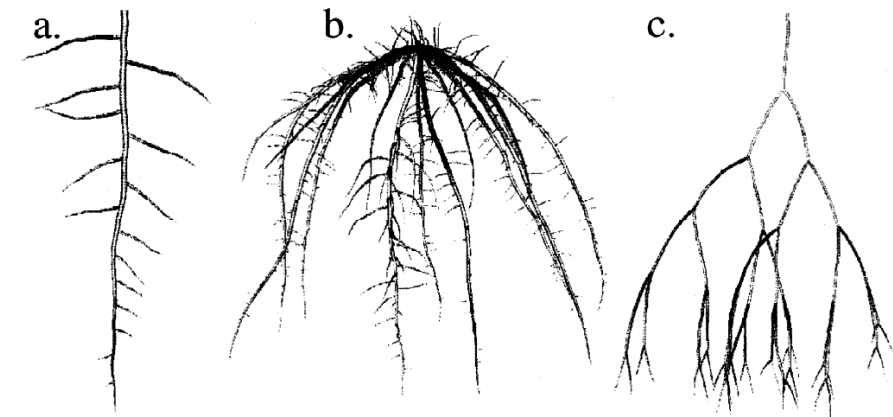
- 3D-Geometric models
- Based on a number of predefined (probabilistic) geometric rules, e.g.:
 - Number of branches
 - Branching length
 - Branching angles

ROOTMAP
 (The Australian School, Diggle, Plant & Soil, 1988)



Includes some kinematics functions and generates “solid” 3-D roots

SIMROOT
 (The American School, Lynch et al., Plant & Soil, 1997)



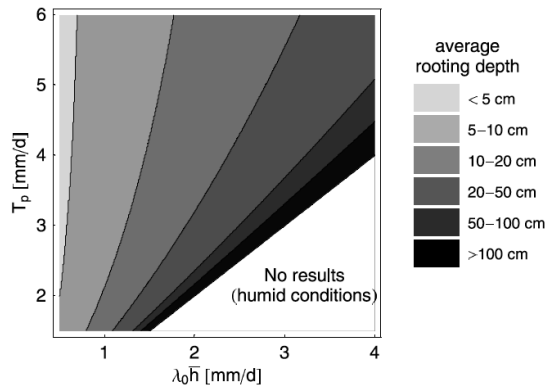
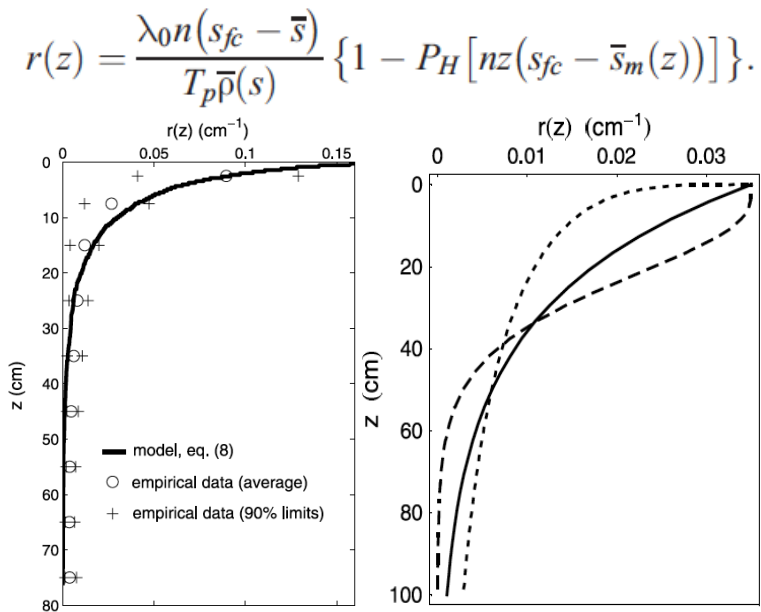
Types I, III, IV

Type VII

Type V, IX

Statistical root architecture models

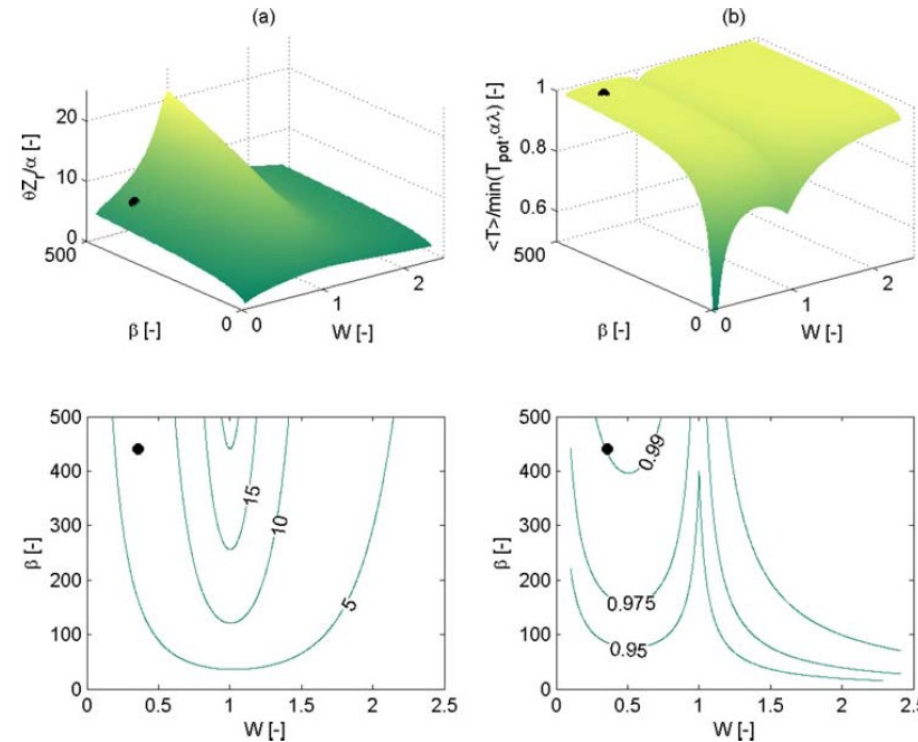
The Italian School, Ecohydrology
(Laio, WRR, 2006,
Laio et al., GRL, 2006)



The American School, Optimization
C cost & benefit (Guswa, WRR, 2008
Guswa, WRR, 2010)

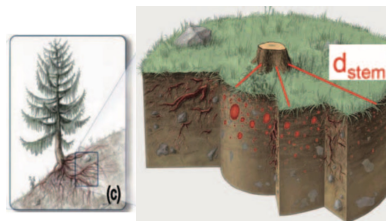
$$\frac{Z_r}{\alpha/\theta} = \frac{\ln\left(W\left[1 + \frac{1}{2}\beta(1-W)^2 \pm \sqrt{\beta(1-W)^2 + \left(\frac{1}{2}\beta(1-W)^2\right)^2}\right]\right)}{(1-W)}$$

$$\beta = \frac{\theta}{\alpha A} = \frac{\theta}{\alpha} \cdot \frac{SRL \cdot WUE}{\gamma_r \cdot RLD} \cdot T_{pot} \cdot f_{seas}$$

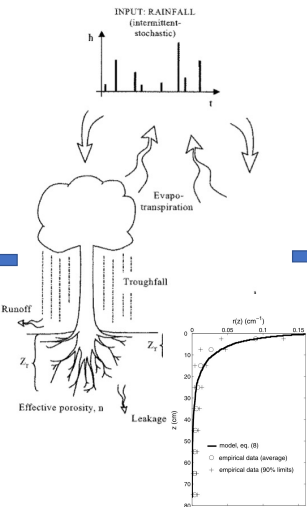


Root Distribution Model

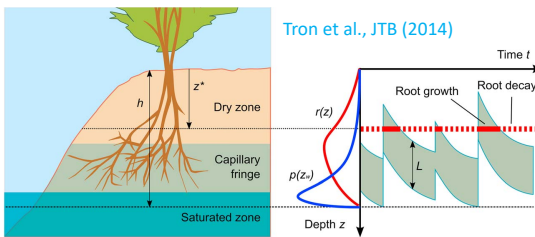
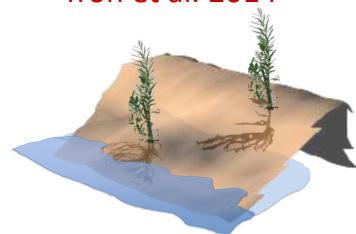
Schwarz et al. 2010



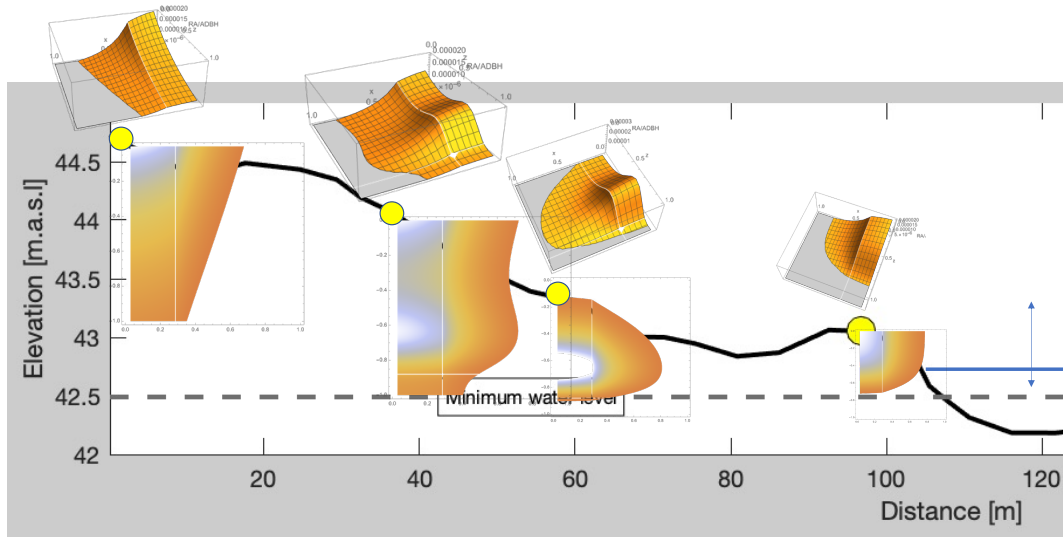
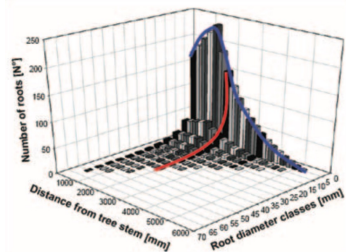
Laio et al. 2006



Tron et al. 2014

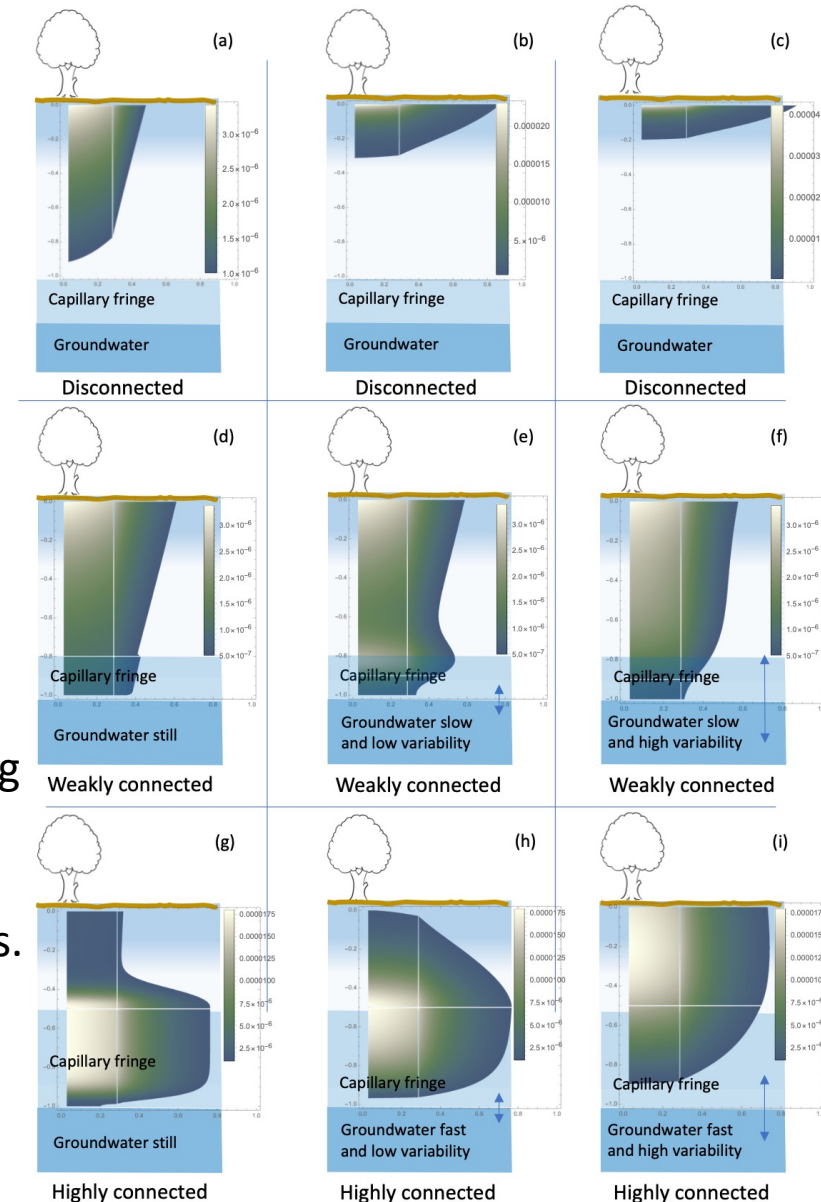


Tron et al., JTB (2014)



Perona et al.,
Ecol. Eng. 2022

Awaiting for testing
to crop plants
under different
irrigation scenarios.
Any interest?



Plant roots biomechanics

ID003 - 40

