# Irrigation and Drainage Engineering

## (Soil Water Regime Management)

(ENV-549, A.Y. 2024-25)

4ETCS, Master option

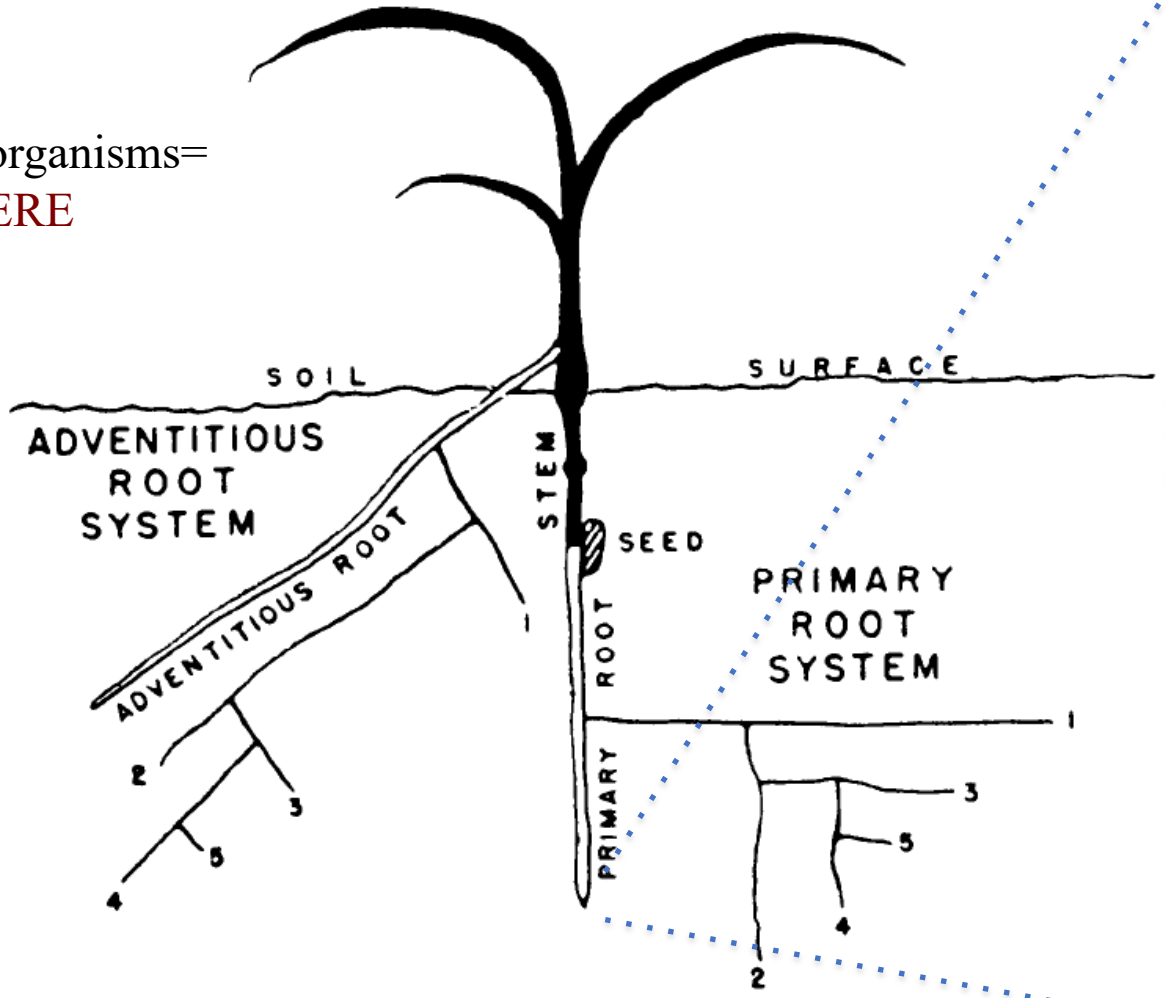
**Prof. Paolo Perona**
Platform of Hydraulic Constructions

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

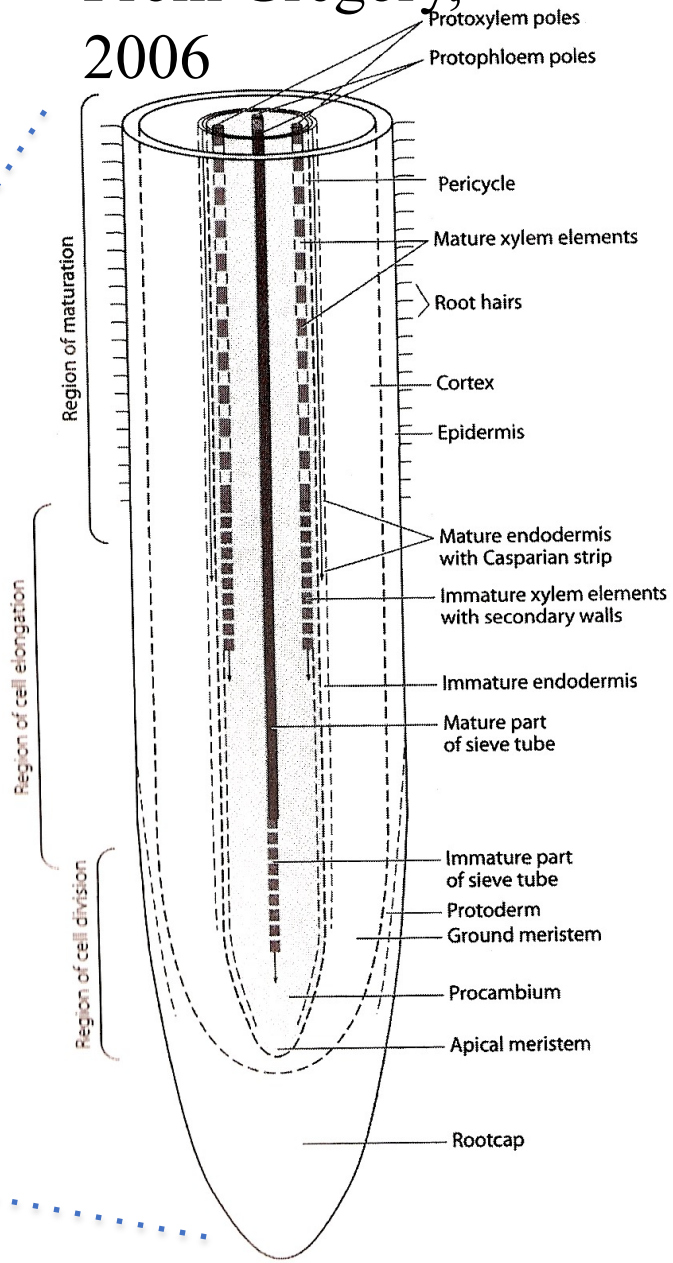
# An essay on the structure and functional roles of the root apparatus

# Root architecture

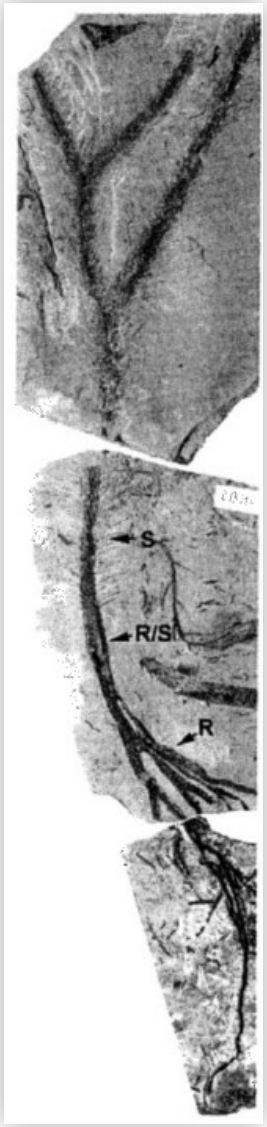
Roots+soil+organisms=
RHIZOSPHERE




From Gregory, 2006



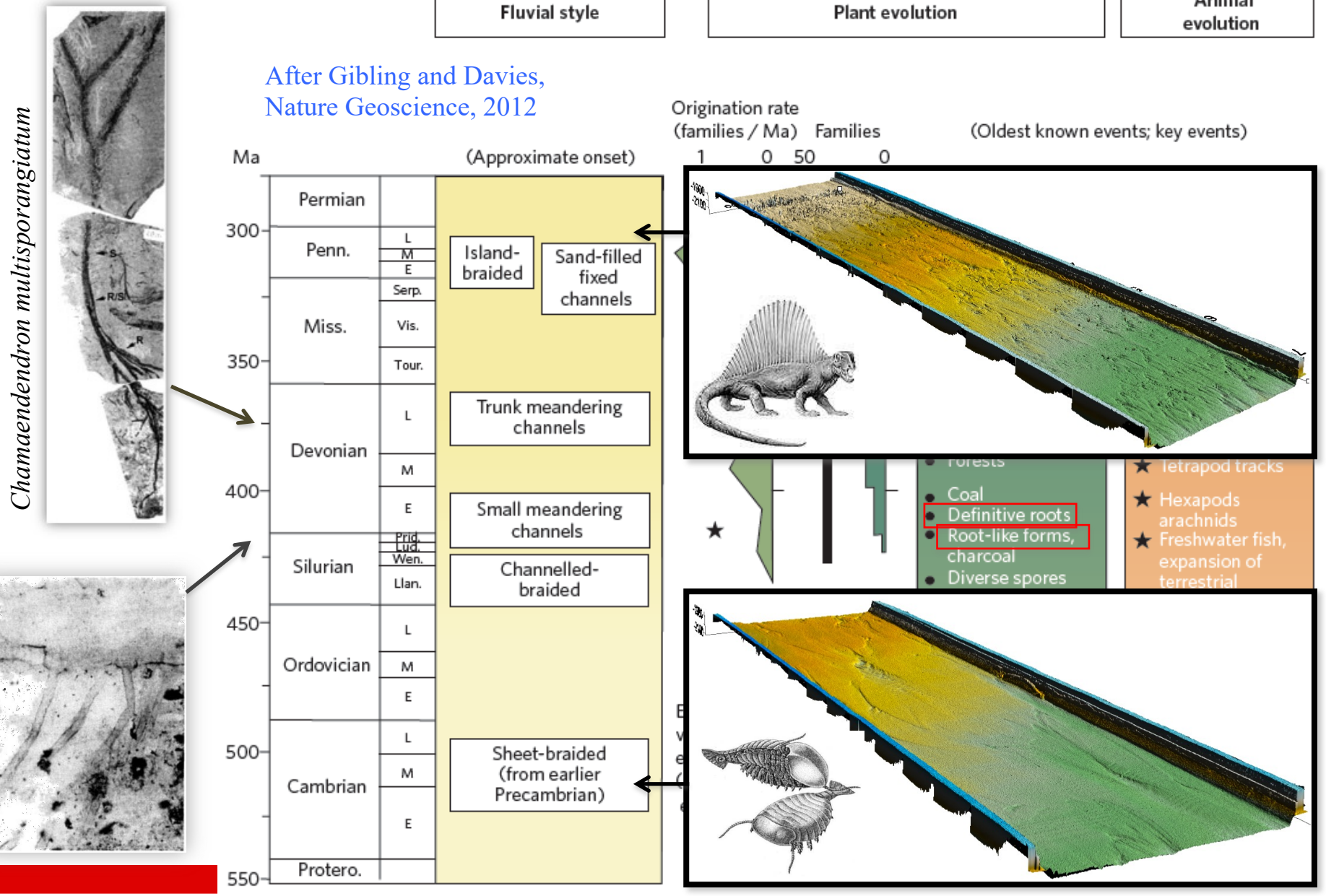
# Early roots



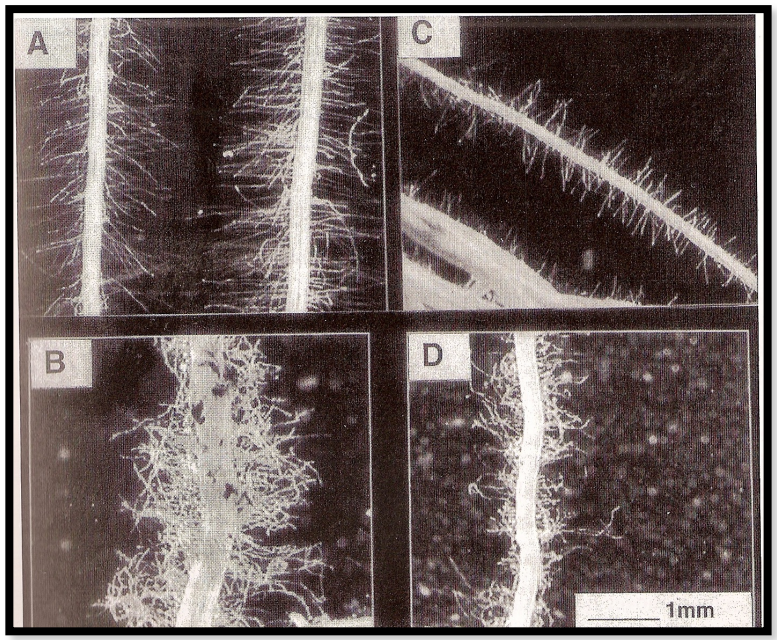

Ancient root systems: (Left) The oldest (396 Mio ys) rooting structure preserved in growth position; (Right) A 377 Mio-ys-old root of *Chamaendendron multisporangiatum* showing multiple bifurcations on both the root (R) and the Stem (S).
Source: Waisel et al., Plant Roots: the hidden half


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

# Paleozoic landscapes shaped by plant evolution



# Root hairs





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

} Root hairs are commonly observed

Phreatophyte: plant obtaining water from near the water table

# Root architecture systems

PRIMARY ROOT SYSTEMS

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

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

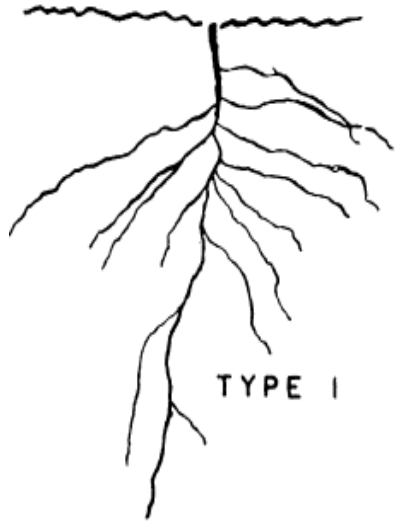
Type III (Xerophytic): Primary root is long and fibrous. Secondary roots short and regularly spread

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

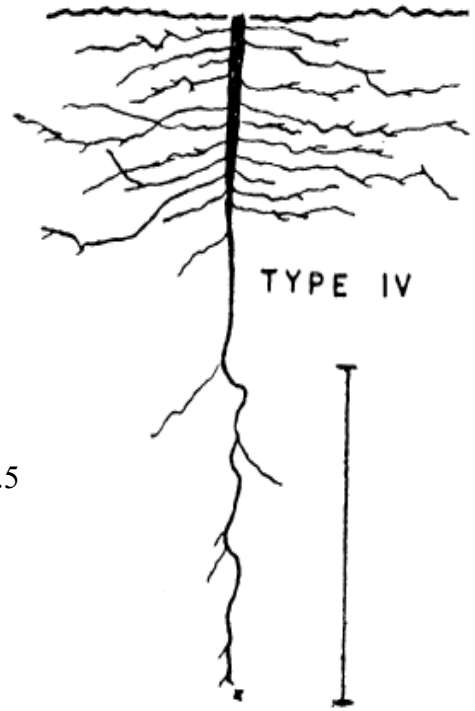
*Amsinchia spectabilis*, scale 1:1





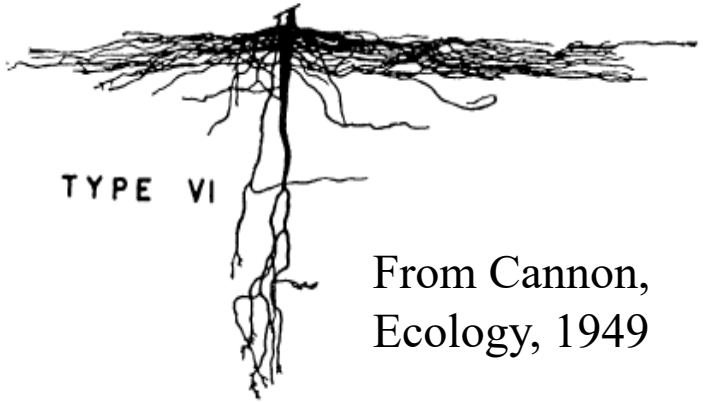
*Disoda papposa*, scale 1:2.5

*Ratibida columnaris*, scale 1:2



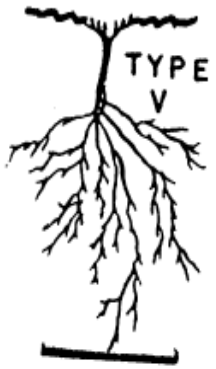

*Castanea Tungurutt*, scale 1:400


*Altingia excelsa*, scale 1:400




From Cannon, Ecology, 1949

*Eritchium argenteum*, scale 1:10

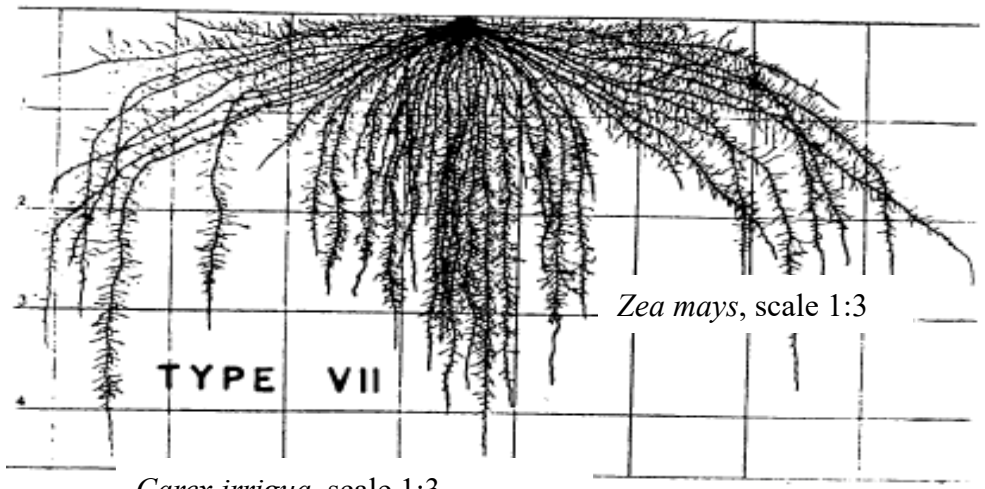


# Adventitius root systems

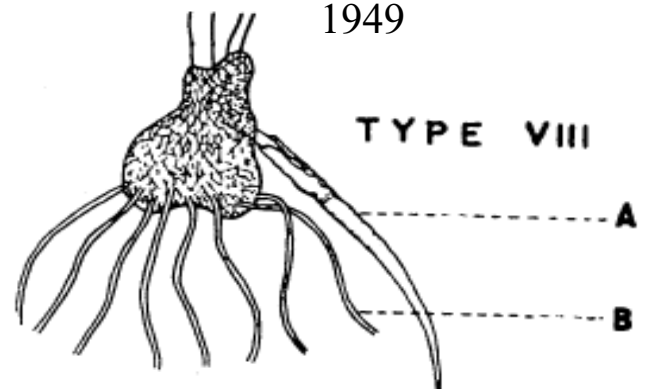
Type VII (Mesophytic and hydrophytic): Group adventitous roots on short horiz or vertic shoot axis
Type VIII (Mesophytic): Centralized multiformal root system with contractile (A) and absorbing-anchoring (B) roots

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:

From Cannon, Ecology, 1949

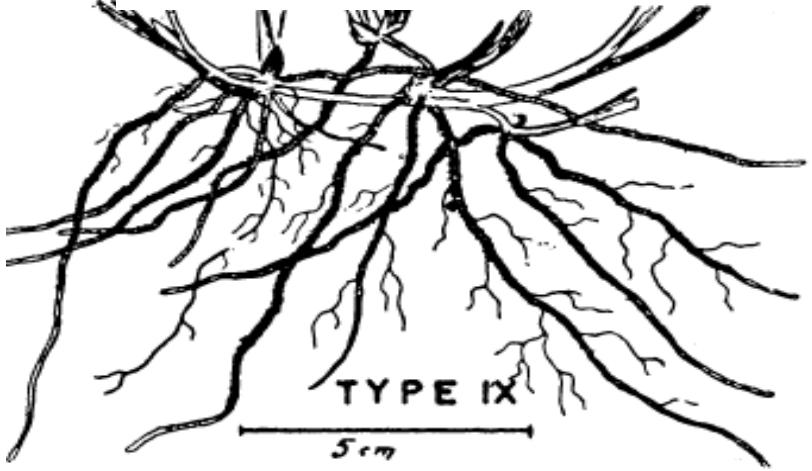



*Zea mays*, scale 1:3

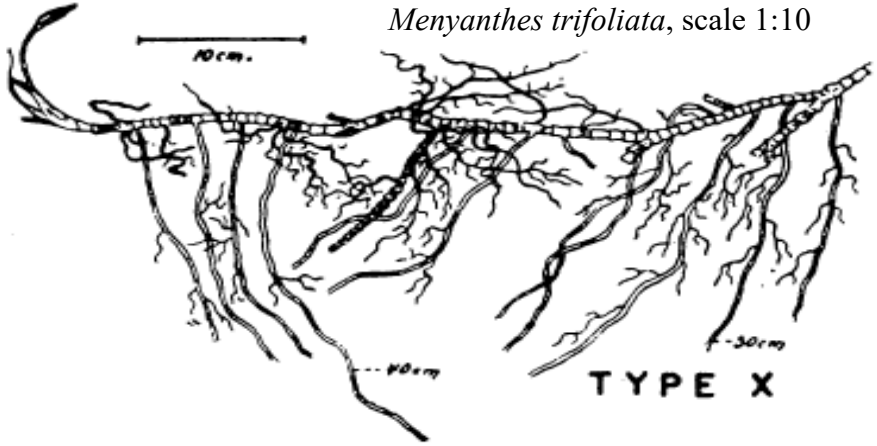



*Brodiaea lactea*, scale 1:4

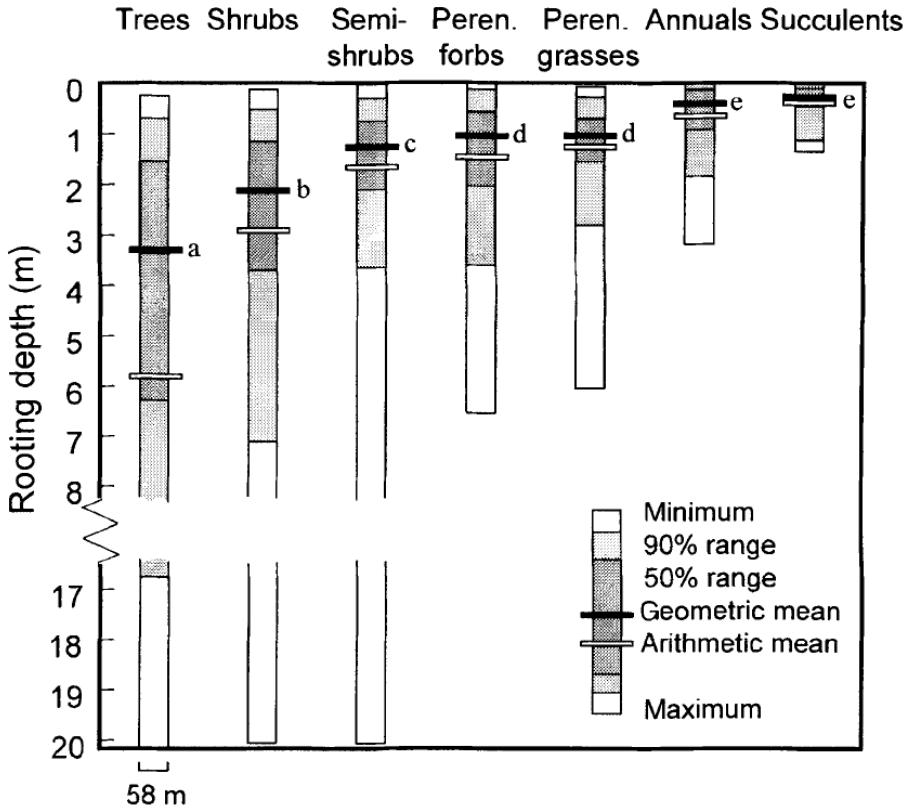
*Carex irrigua*, scale 1:3




*Menyanthes trifoliata*, scale 1:10

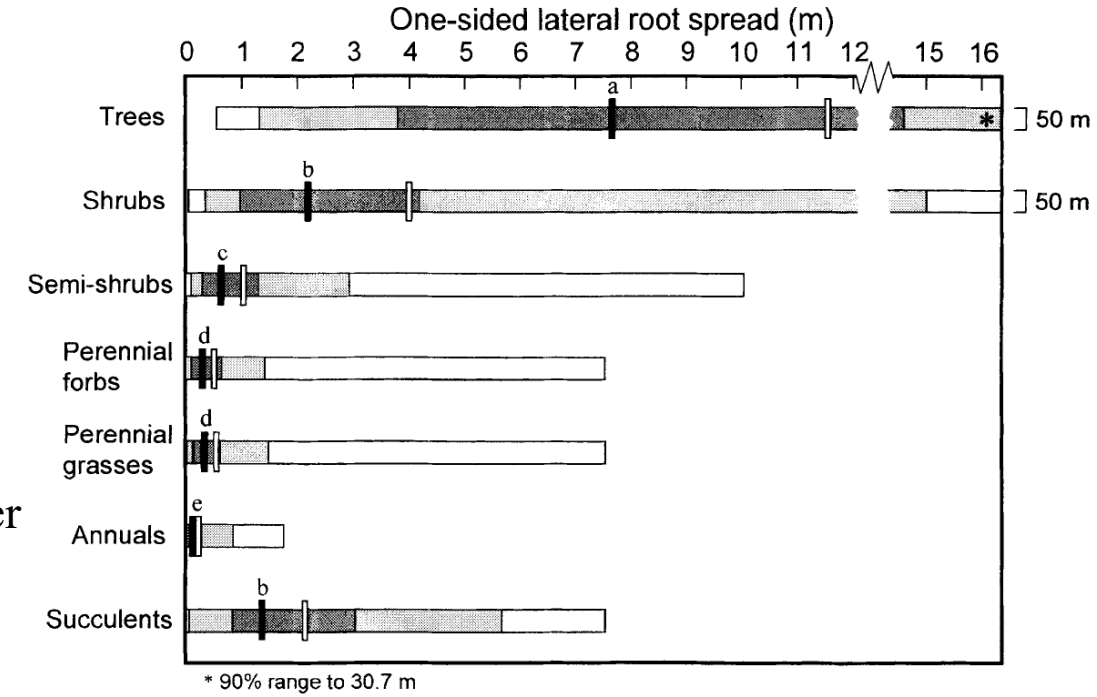


# Example root statistics



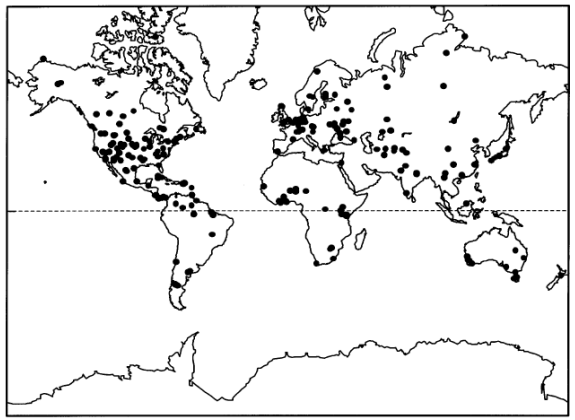

After Schenk and Jackson, J of Ecology, 2002

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

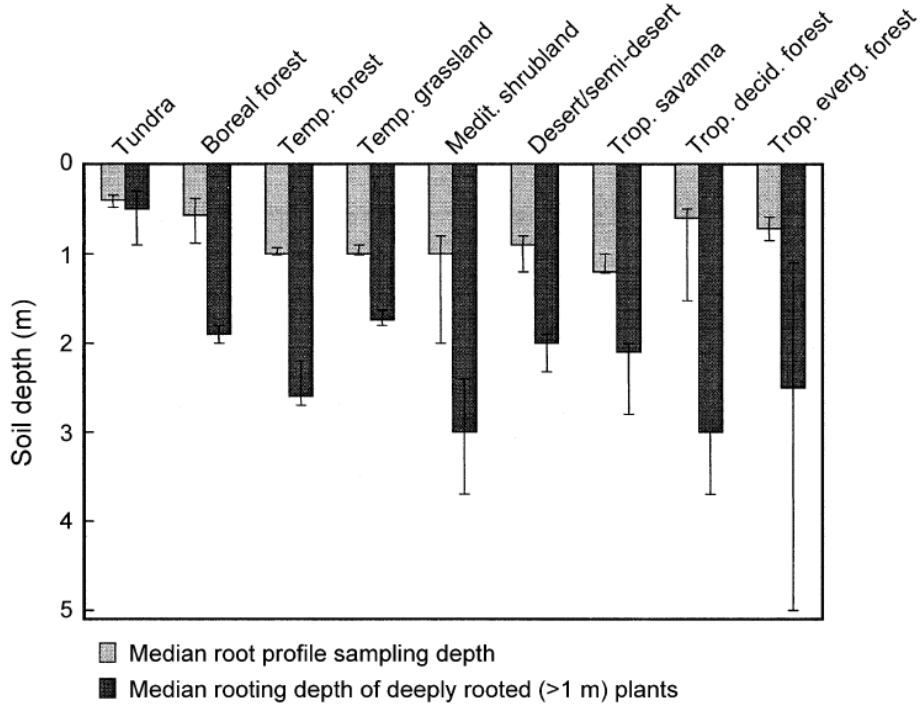


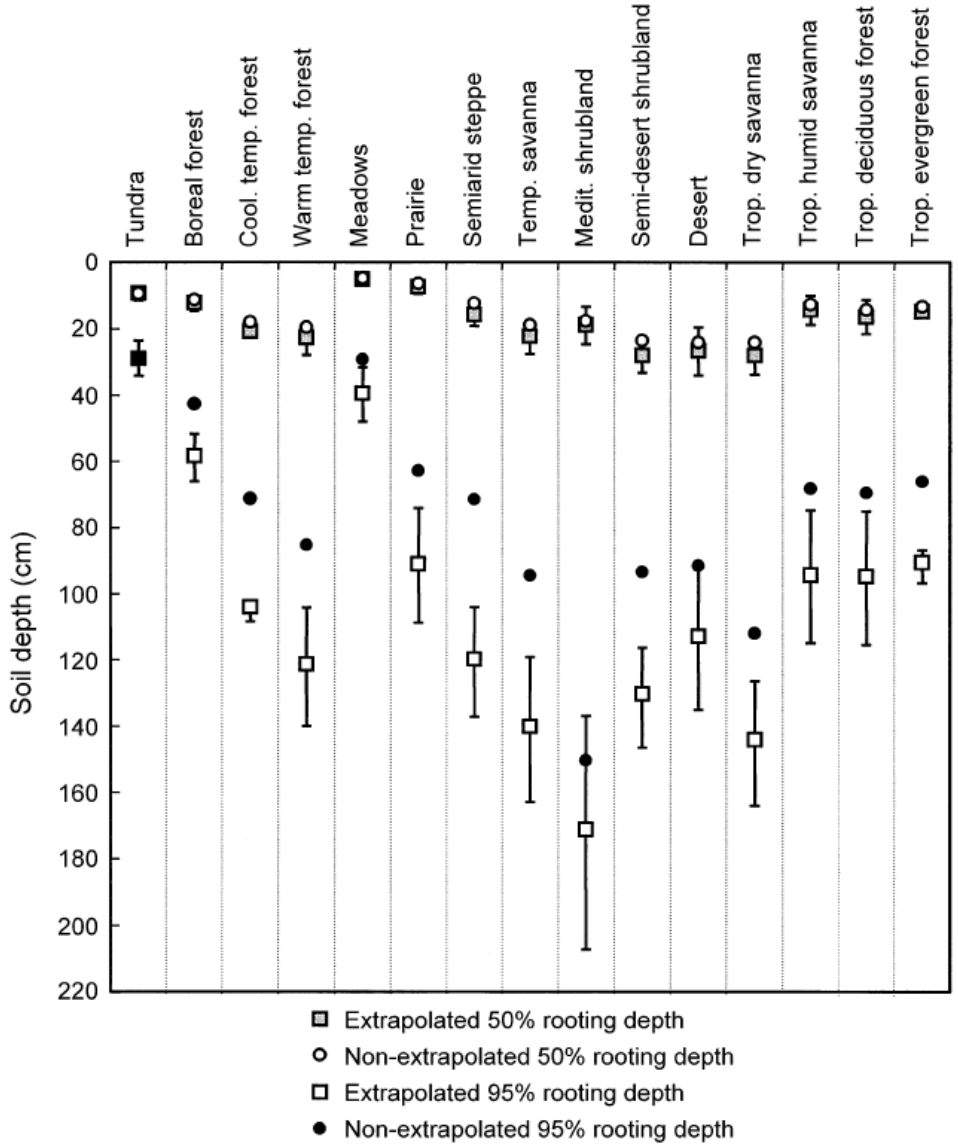

Classification of lateral root spread statistics for plants growing in water limited ecosystems

# Biogeography of roots



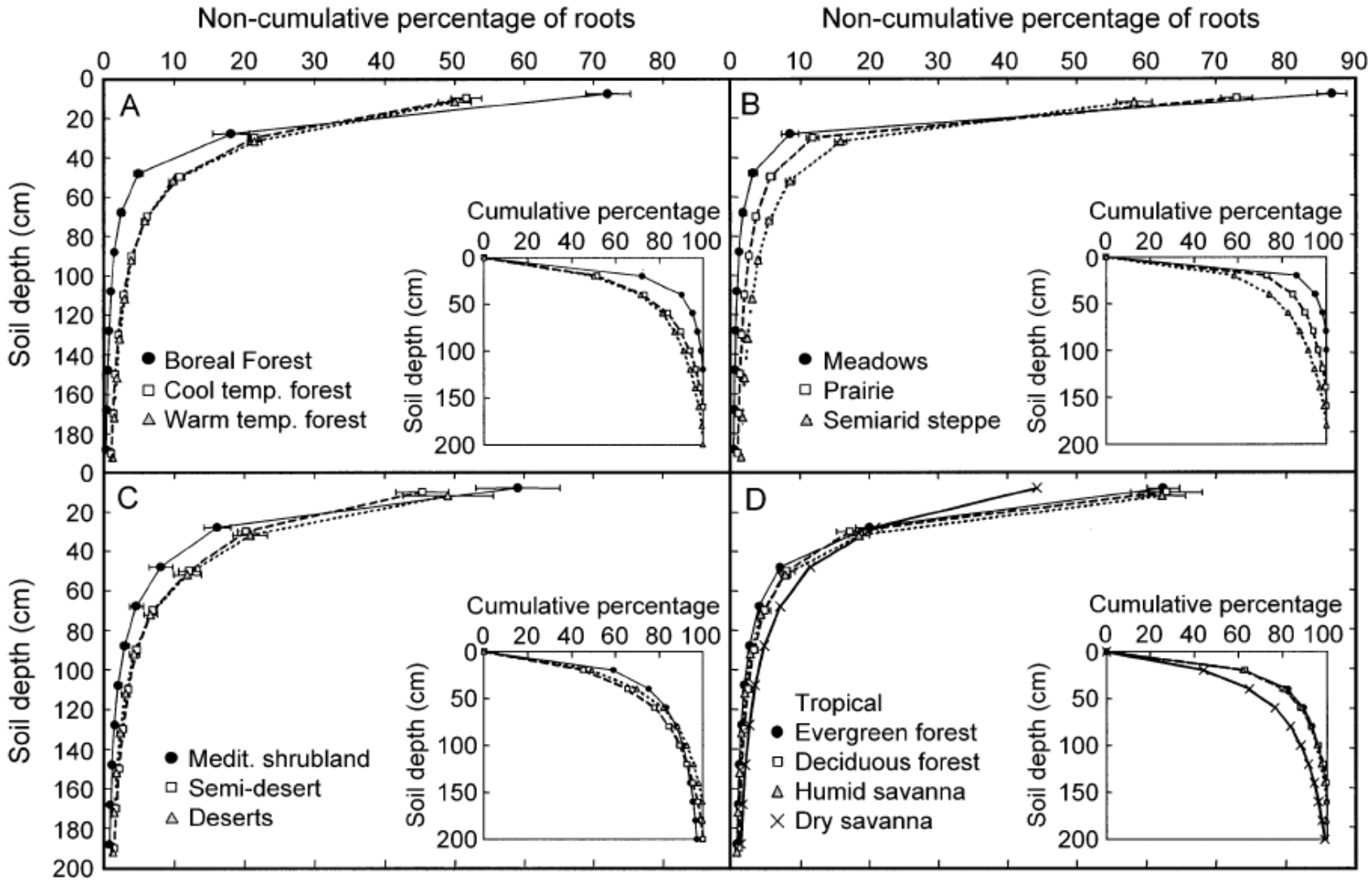
After Shenk and Jackson, Ecol. Monogr., 2002



# Vertical root distribution

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



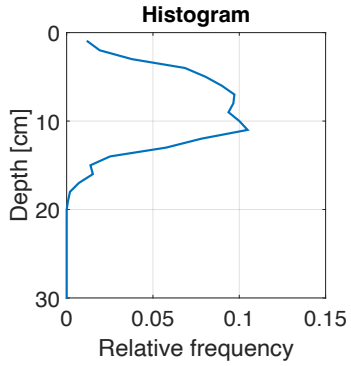
# Root growth of some crop plants

## Cabbage

Edited black and white image

Surface root area: 82.6 cm$^2$

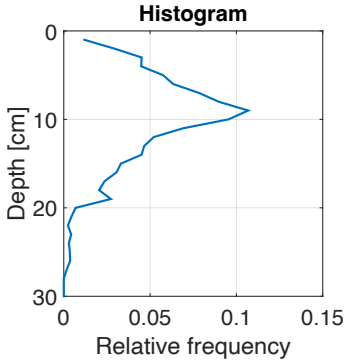
Day 60




Edited black and white image

Surface root area: 183.1 cm$^2$

Day 90




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

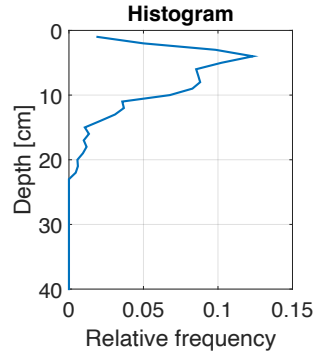
In order to understand why we need to first learn about roots' "tropism"

## Eggplant

Edited black and white image

Surface root area: 23.3 cm$^2$

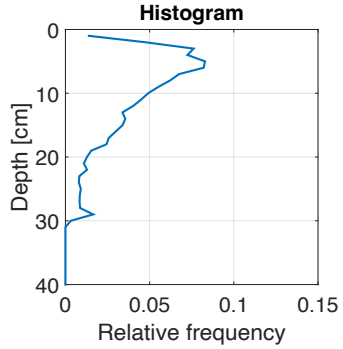
Day 30




Edited black and white image

Surface root area: 92.5 cm$^2$

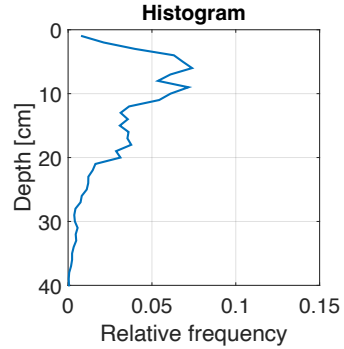
Day 55




Edited black and white image

Surface root area: 89.4 cm$^2$

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 impedence (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)

Pea root growth


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

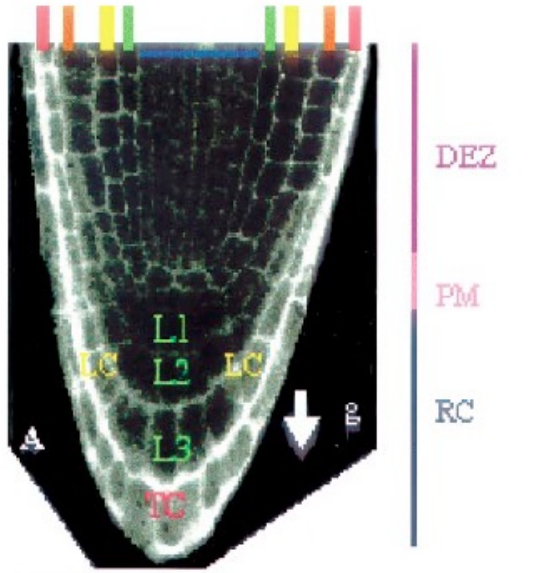
# Example: gravitropism

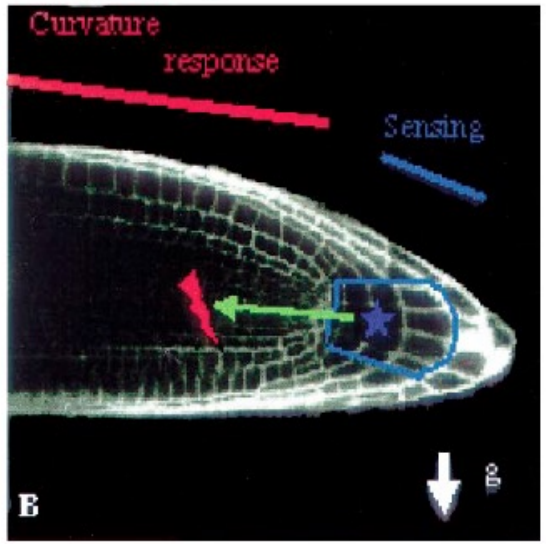
After Boonsirichai et al., Ann. Rev. Plant Biol., 2002

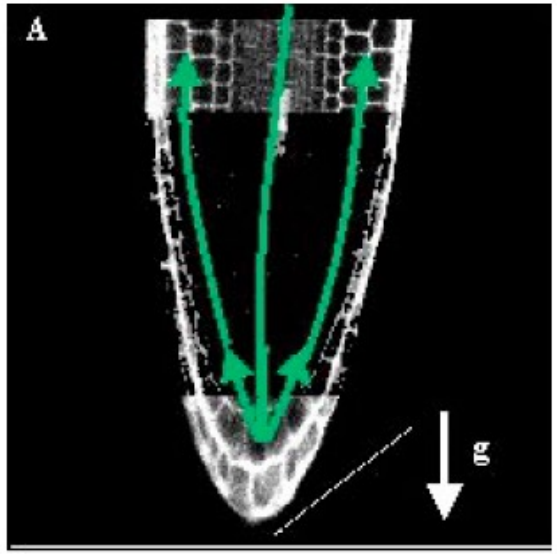
Root cap cells are like gravity sensors

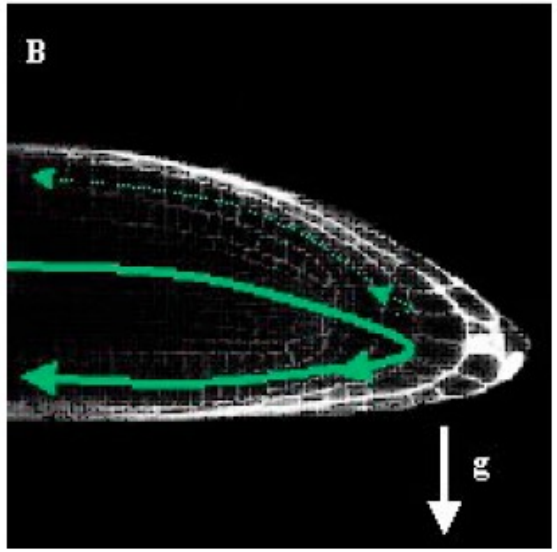
Mechanism (Fountain model): hormonal fluxes (Auxin) and sedimentation of starch-filled amyloplast within statocytes (cells of root cap)

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



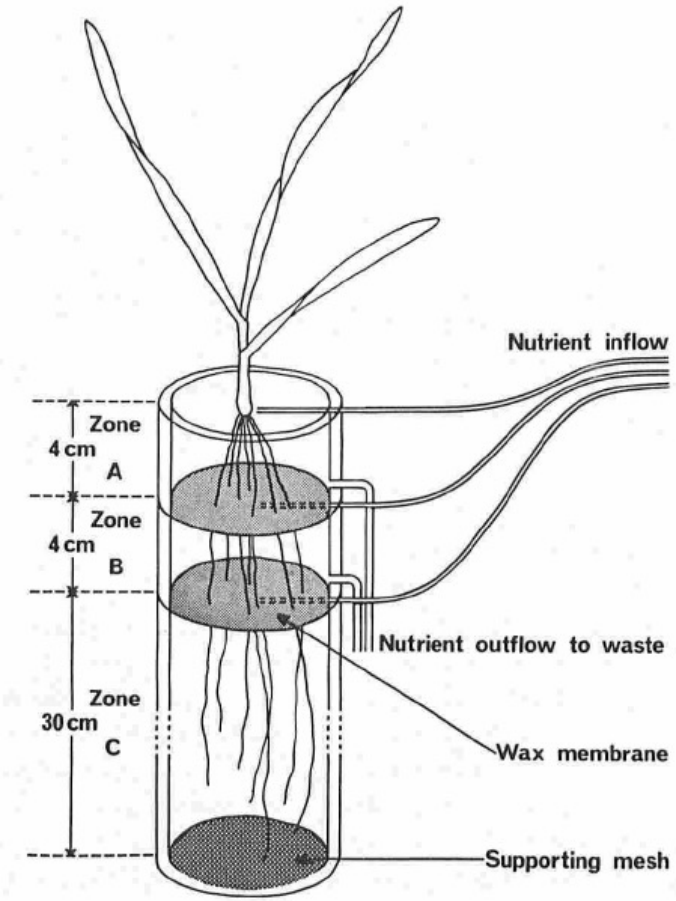



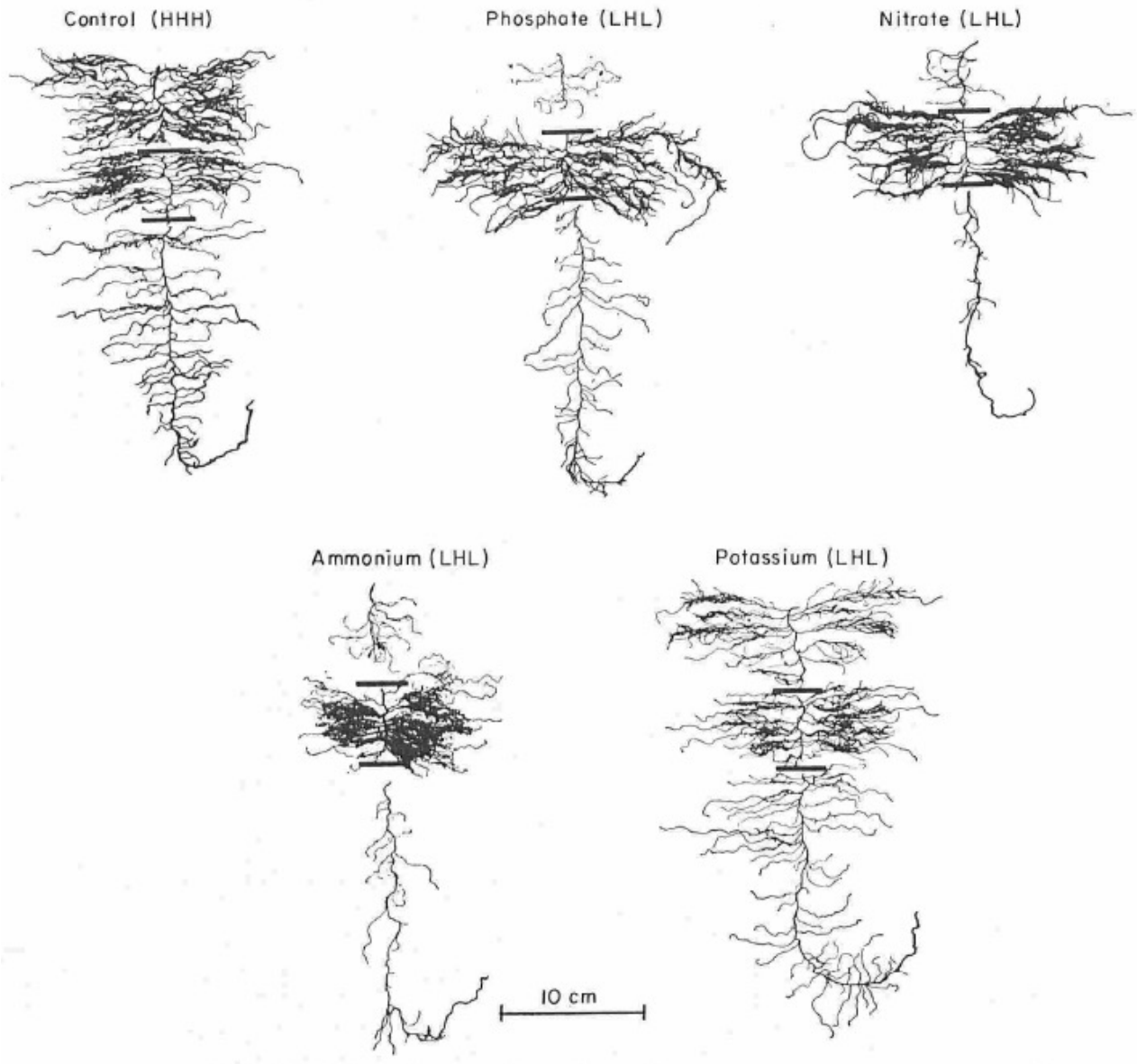



# Example: chemotropism

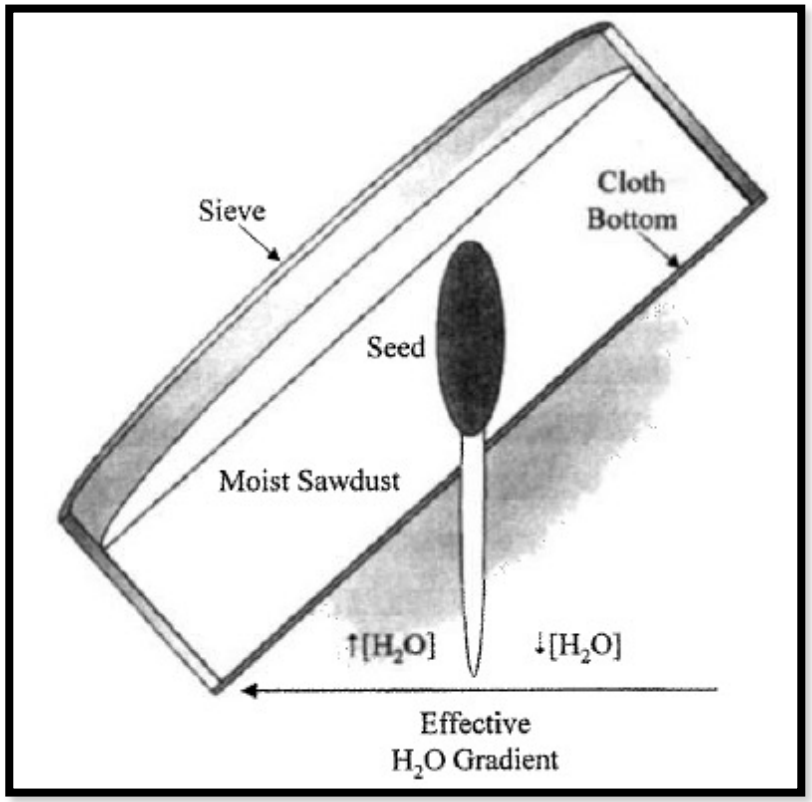
After Drew, New Phyt., 1975

Barley plants grown for 21 days in controlled environment

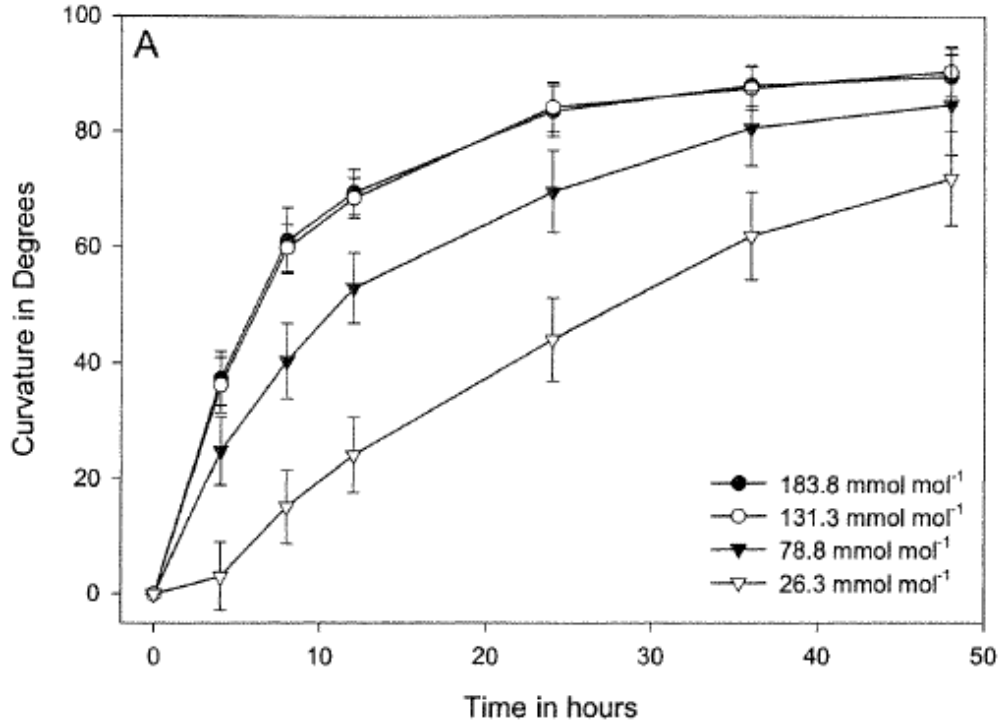


# Example: hydrotropism and oxitropism



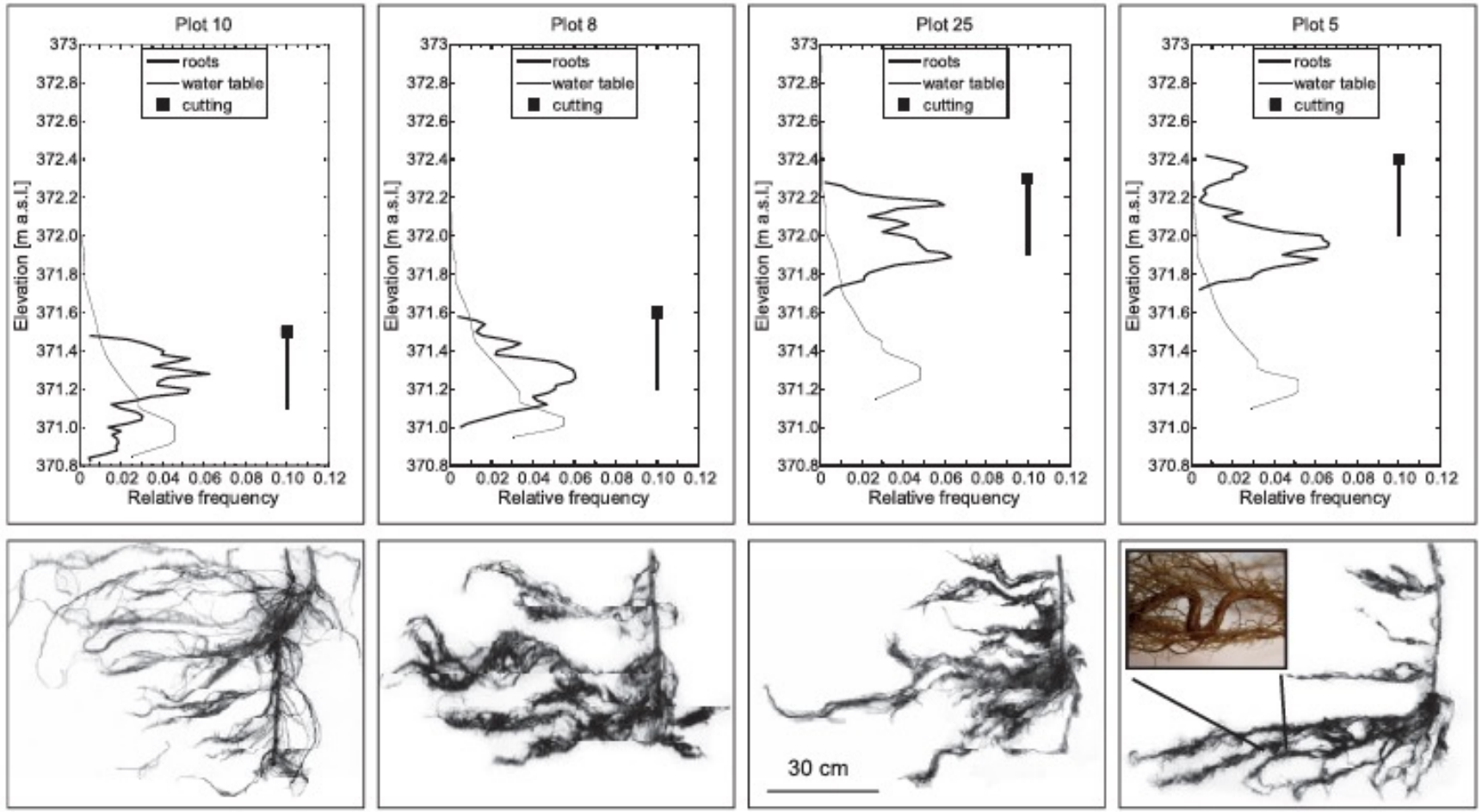

Sachs' experiment (1872) to demonstrate hydrotropism




Porterfield and Musgrave, 1998. Roots curvature change and growth proceeds toward region with higher $O_2$ concentration

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

# Hydrotropism *vs* oxitropism

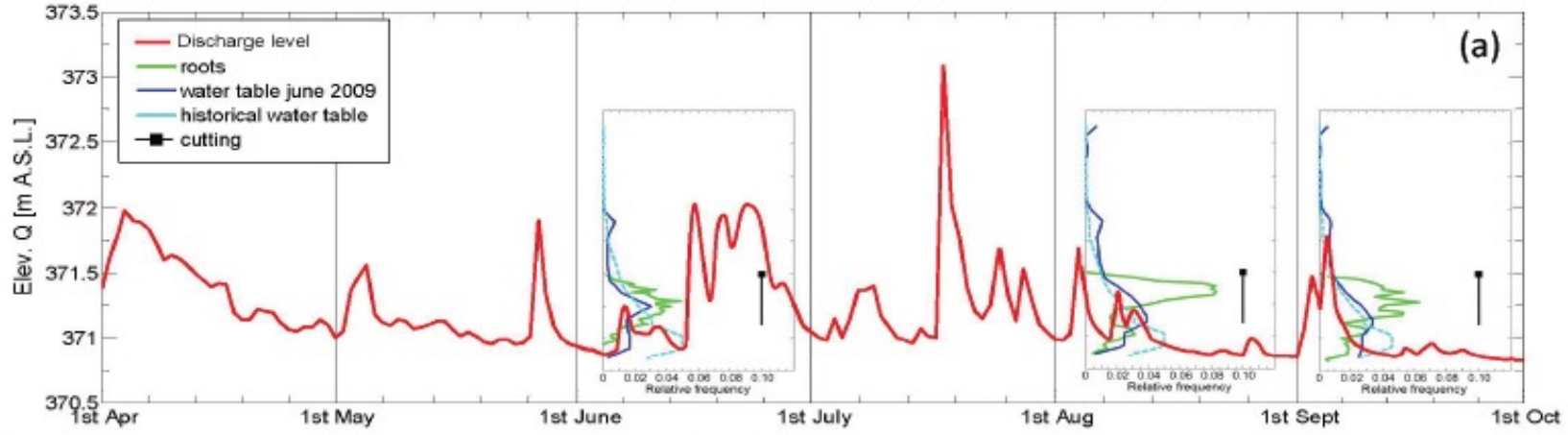


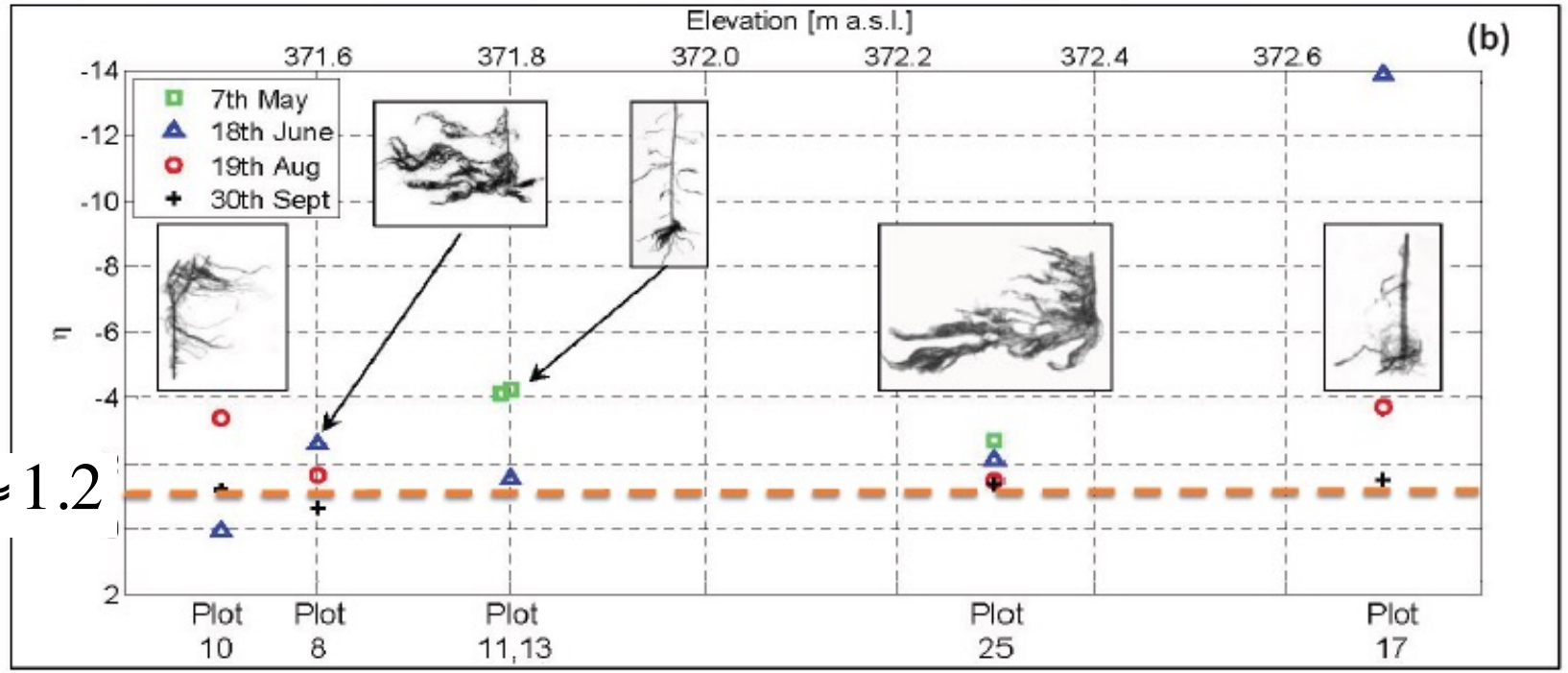

After Pasquale et al., Ecol. Eng. 2012

Assumptions (confirmed):

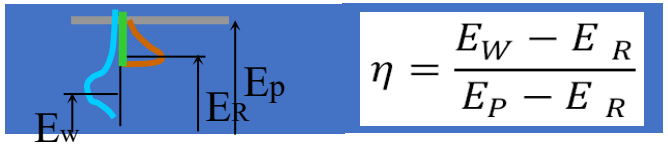
- Nutrient availability is not a limiting factor for plants to grow (verified from soil samples)
- Precipitation is uniformly distributed at the island scale

# Dimensionless scaling



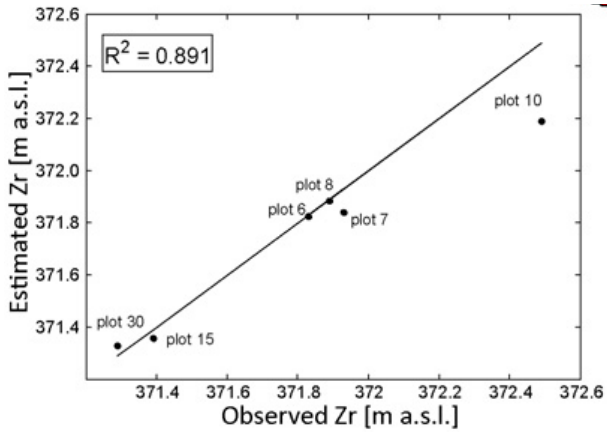




$\eta \approx 1.2$

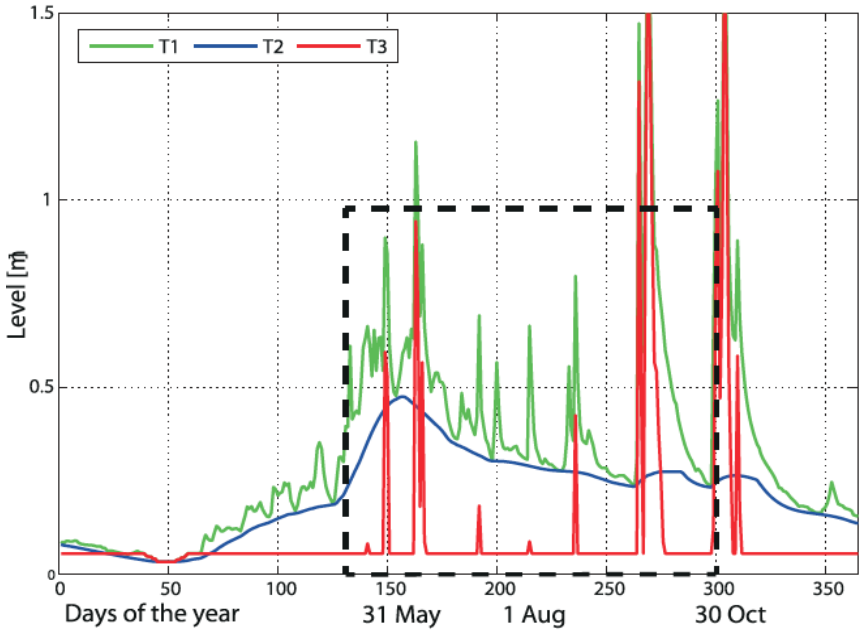



After Pasquale et al., Ecol. Eng. 2012

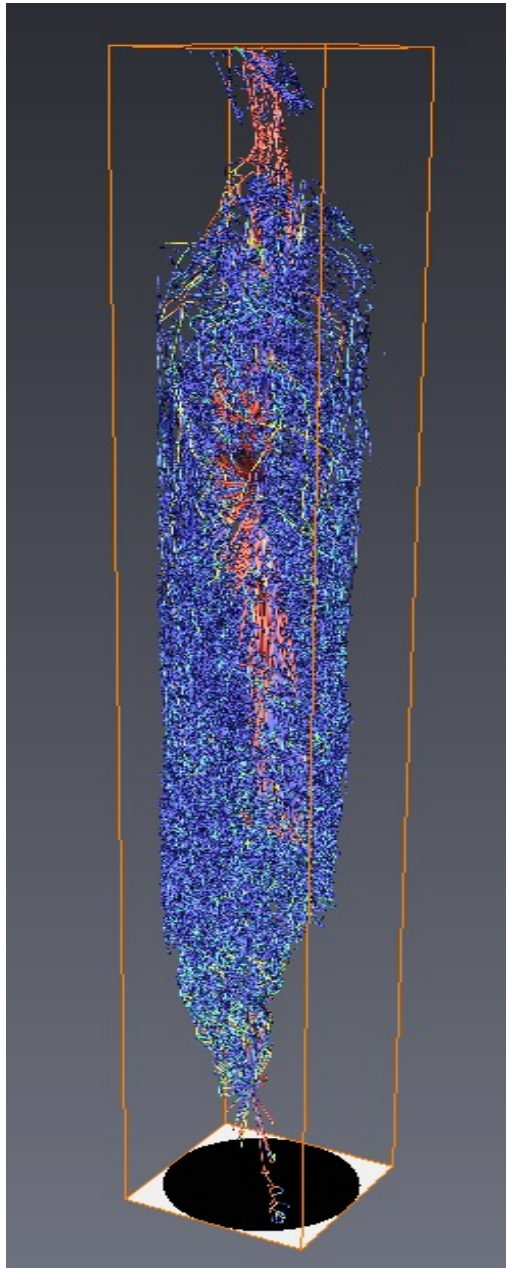
Inter-seasons prediction

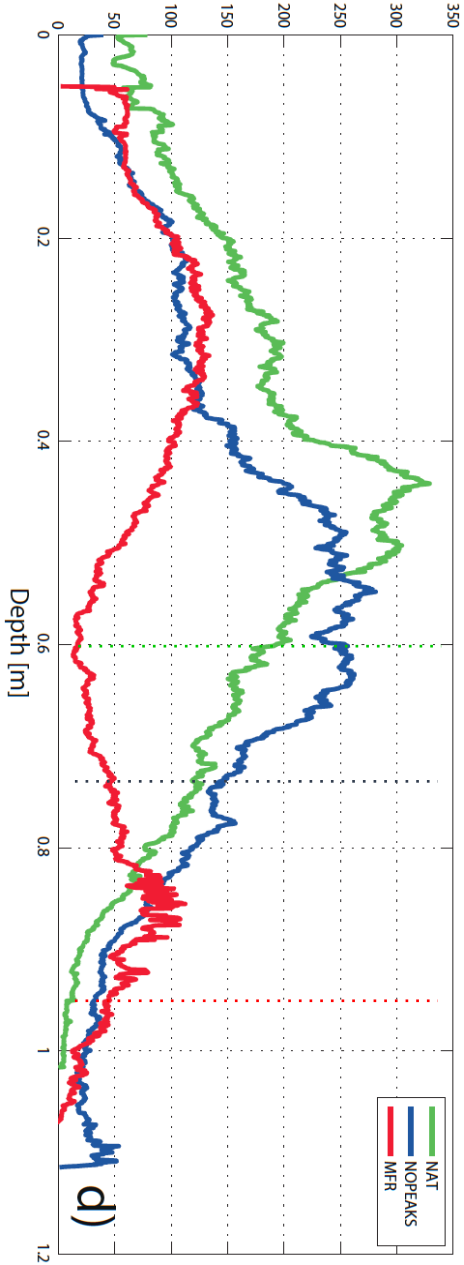


# Response to changing water regime



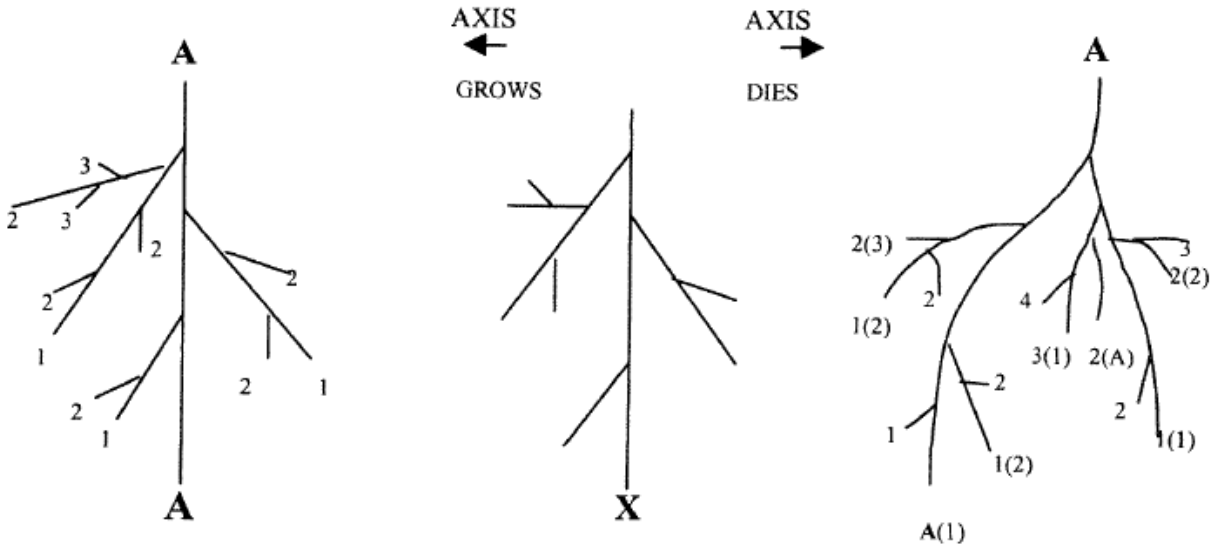

Gorla et al., WRR, 2015

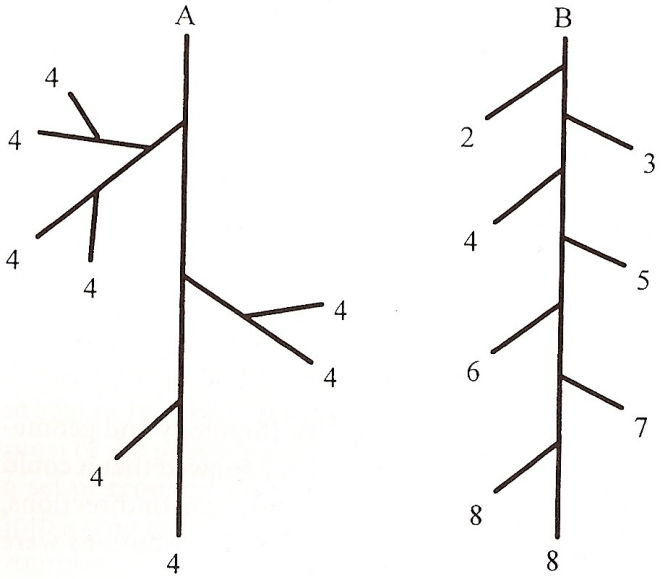




# Explicit root architecture models

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



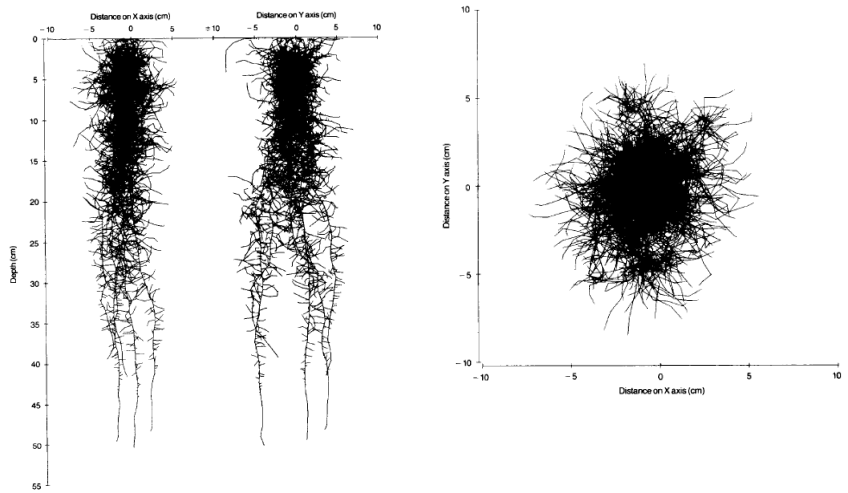




Scheme of two major root architectures topologies: (A) dichotomous; (B) herringbone (from Smit, 2000). Numerals are exterior path length, the number of links in the path from each exterior link to the base link

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

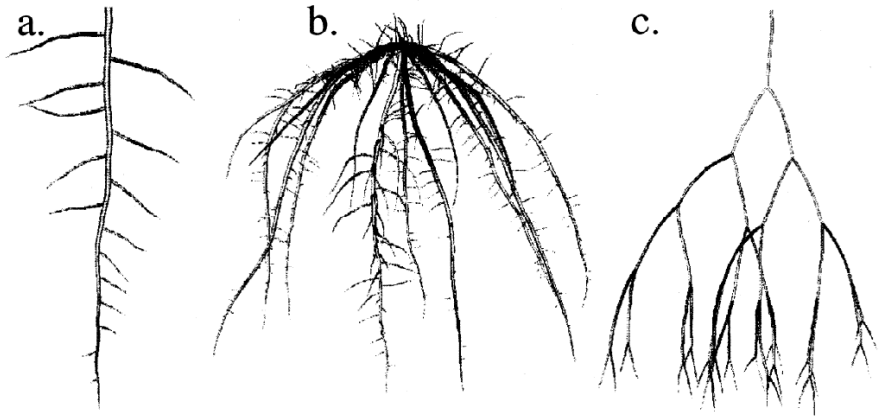
- 3D-Geometric models
- Based on a number of predefined (probabilistic) geometric rules, e.g.:
  - Number of branches
  - Branching length
  - Branching angles

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)

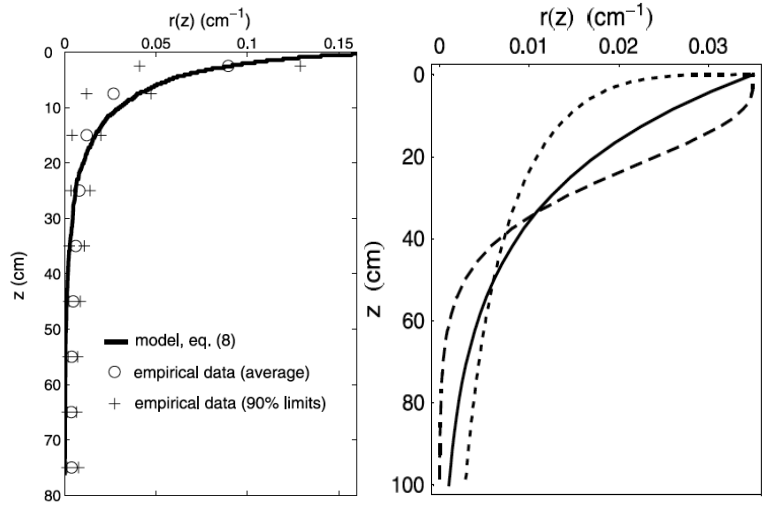


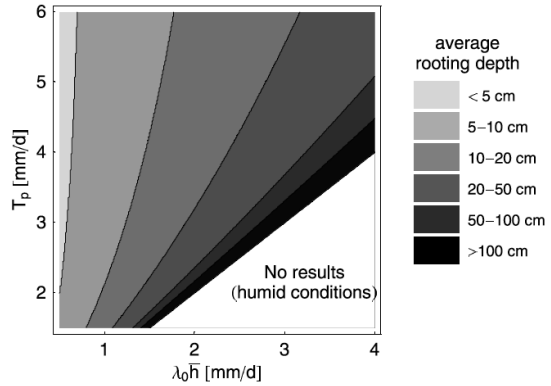

Types I, III, IV  Type VII  Type V, IX

# Statistical root architecture models

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

$$r(z) = \frac{\lambda_0 n\left(s_{fc} - \bar{s}\right)}{T_p \bar{\rho}(s)} \left\{1 - P_H\left[nz\left(s_{fc} - \bar{s}_m(z)\right)\right]\right\}.$$

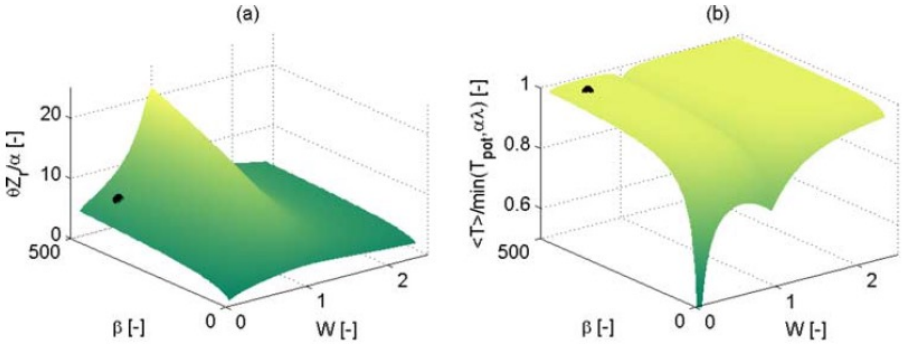


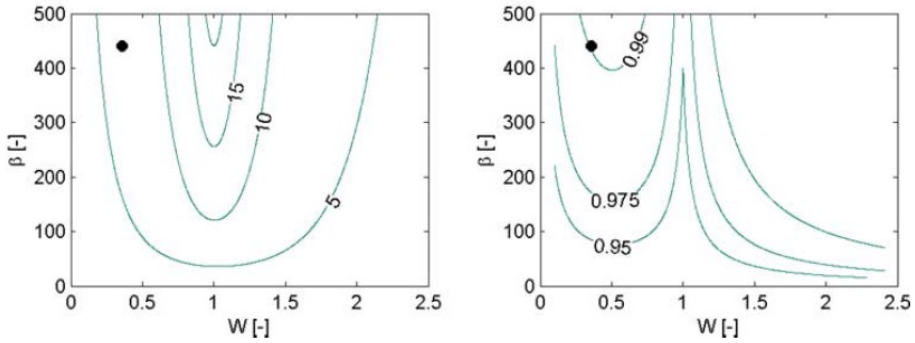




The American School, Optimization
C cost & benefit (Guswa, WRR, 2008
Guswa, WRR, 2010)

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

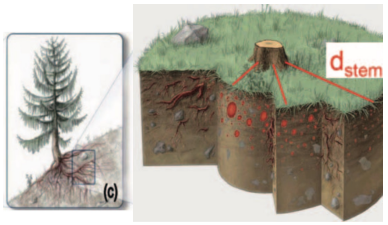
$$\beta = \frac{\theta}{\alpha A} = \frac{\theta}{\alpha} \cdot \frac{SRL \cdot WUE}{\gamma_r \cdot RLD} \cdot T_{pot} \cdot f_{seas}$$

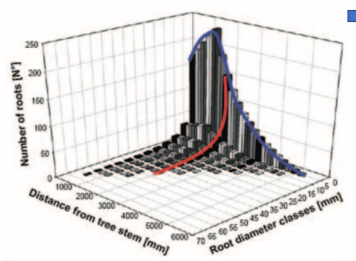


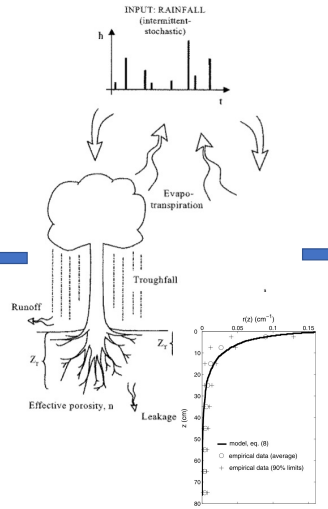
# Root Distribution Model

Schwarz et al. 2010

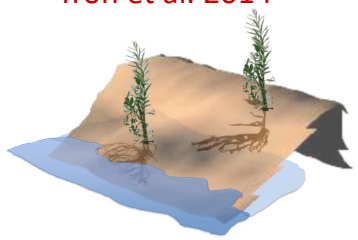


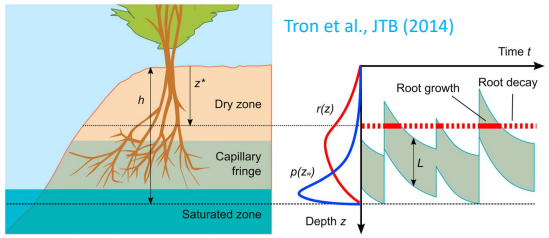




Laio et al. 2006

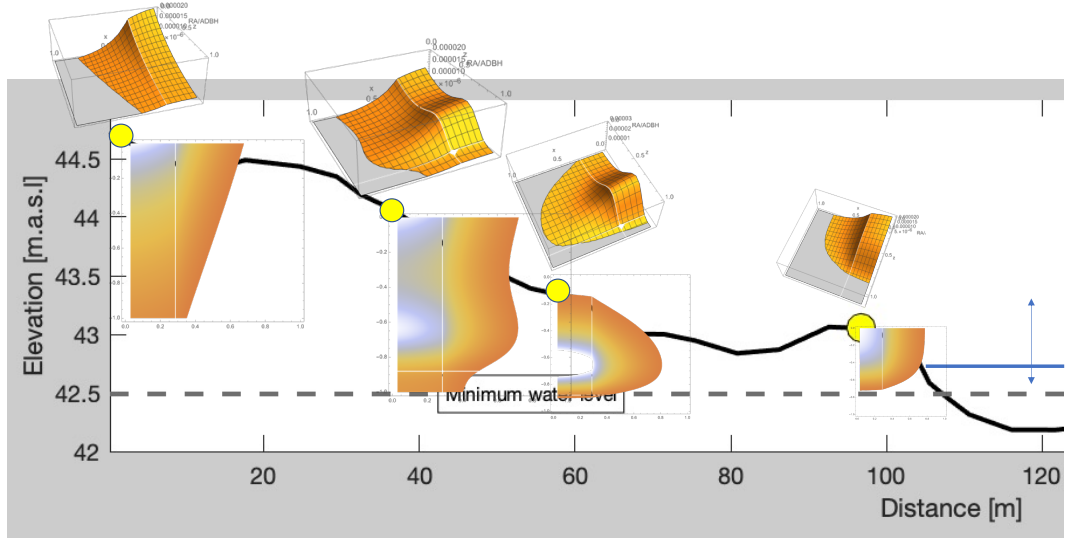



Tron et al. 2014



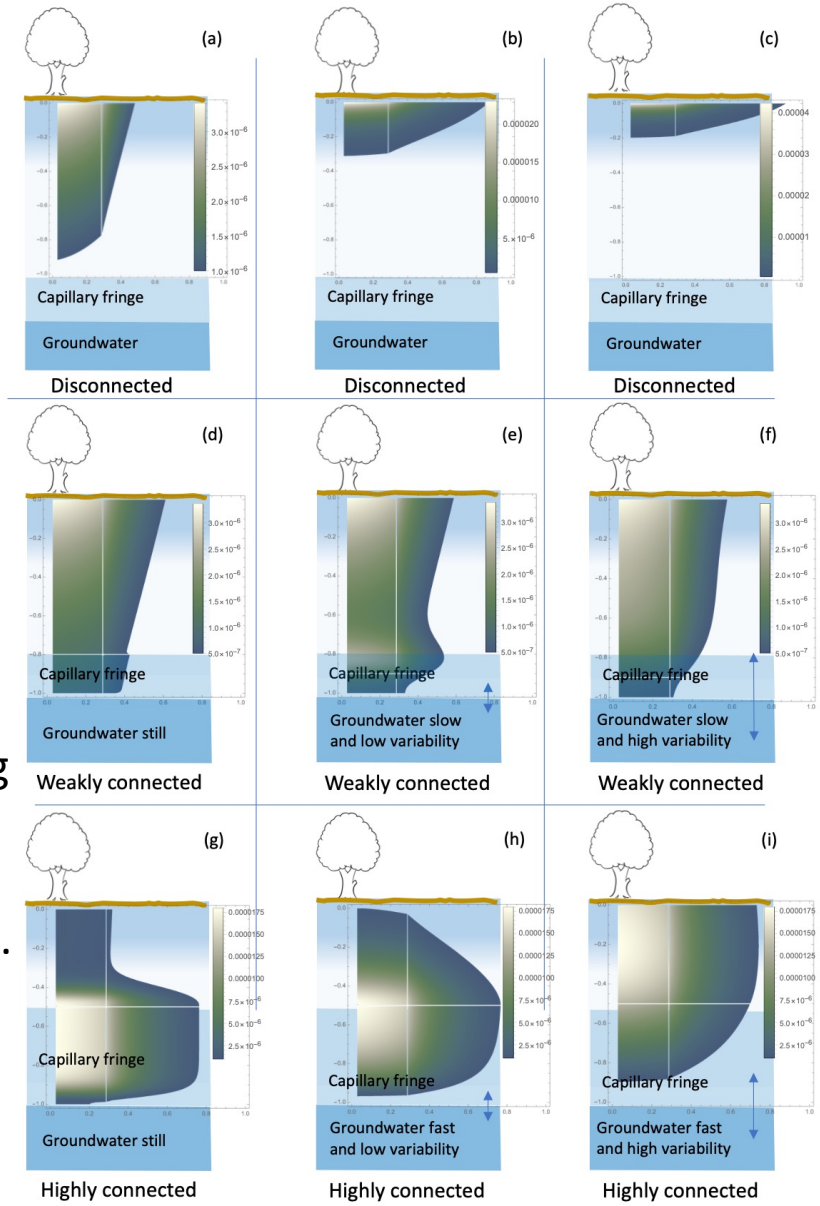



Tron et al., JTB (2014)




Perona et al., Ecol. Eng. 2022

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



# Plant roots biomechanics