Root growth in almond trees

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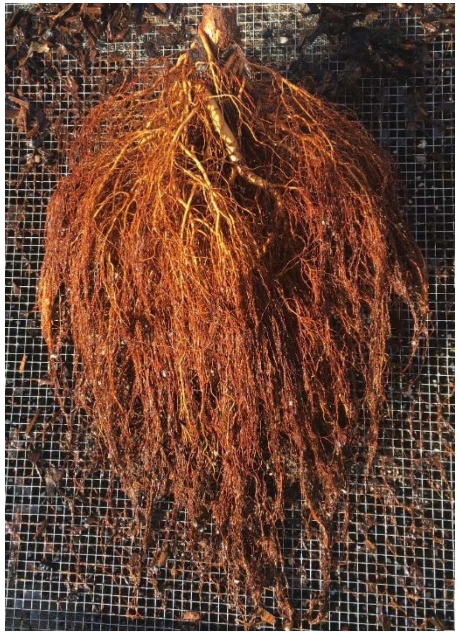
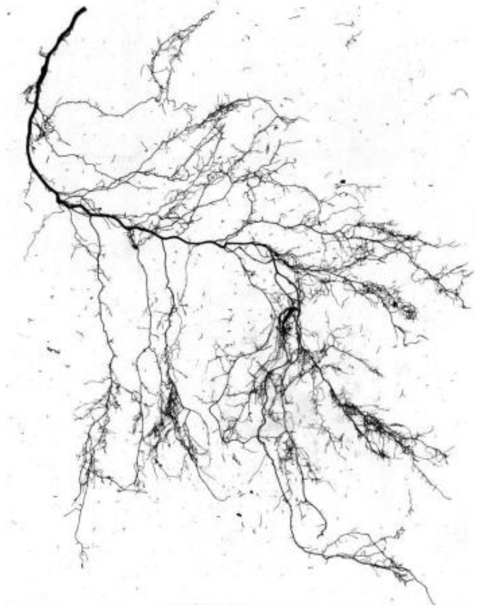
Types of roots



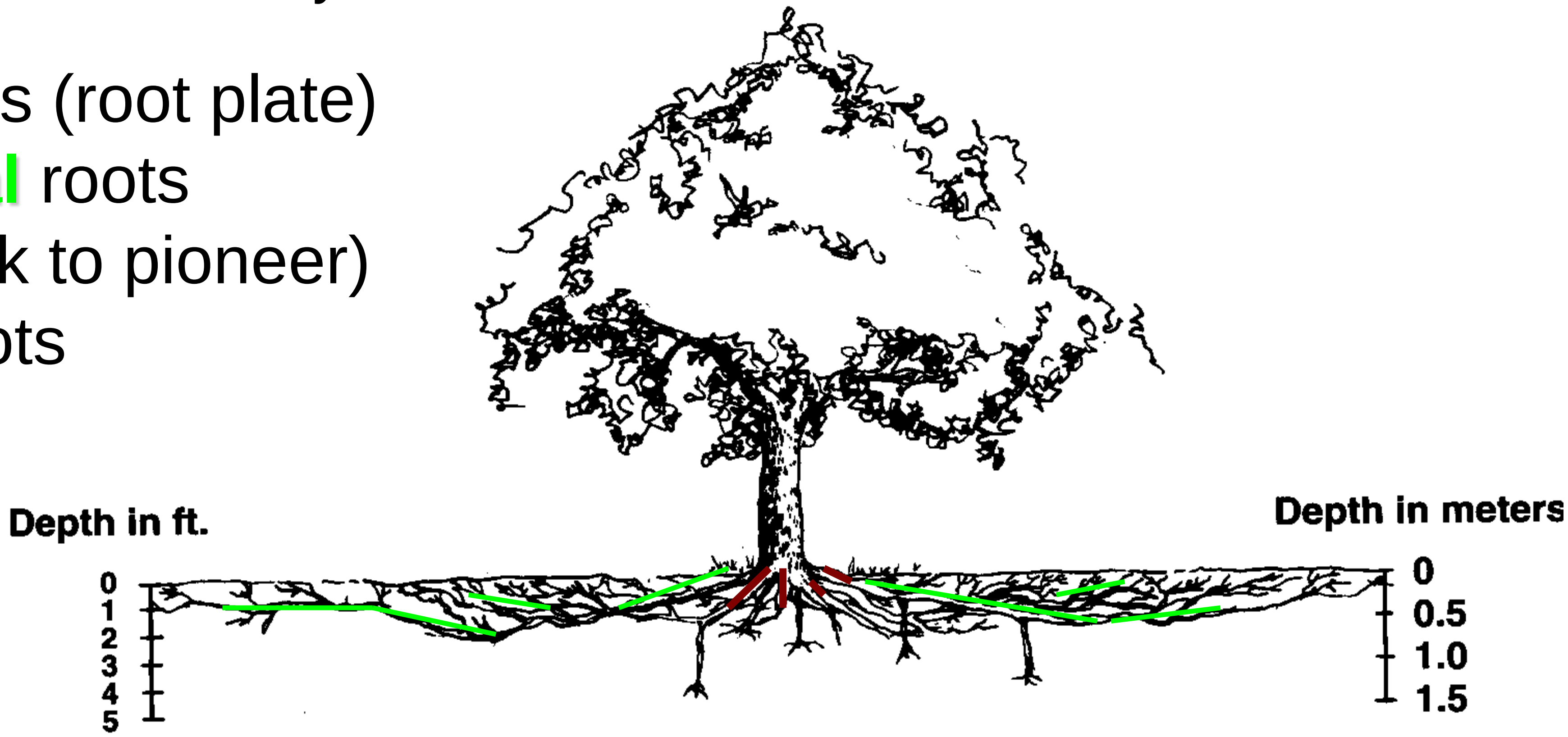
- Large diameter framework roots – anchorage
  - Majority of root biomass
- Smaller diameter exploratory roots – soil exploration/anchorage
- Very fine diameter, short-lived roots – water uptake, nutrient absorption
  - Majority of root length



Woody Root Architecture

The woody part of root systems is a combination of:

Heart roots (root plate)
Horizontal roots
(framework to pioneer)
Sinker roots



Tree root systems can easily extend >2X the height of the tree, and surprisingly, **most tree root systems are not very deep**

Bare root almond root system, one year after planting (Krymsk 86)

Notice that roots respond to pruning at planting very much the way that shoots do → lots of branching at cut tips

Fine roots versus coarse roots

- Fine roots:
  - Equivalent to leaves – acquire resources
  - Direct acquisition of water & nutrients
  - Low mass, high length (high absorptive surface)
  - Short lifespan
  - Signaling (hormones – e.g. production of auxin, cytokinin, abscisic acid, ACC/ethylene)
- Coarse roots:
  - Anchor the plant
  - Framework for soil exploration
  - Transport of water & nutrients (up), redistribute carbohydrates to fine roots
  - High mass, low length (high transport capacity)
  - Long lifespan
  - Storage

Large roots

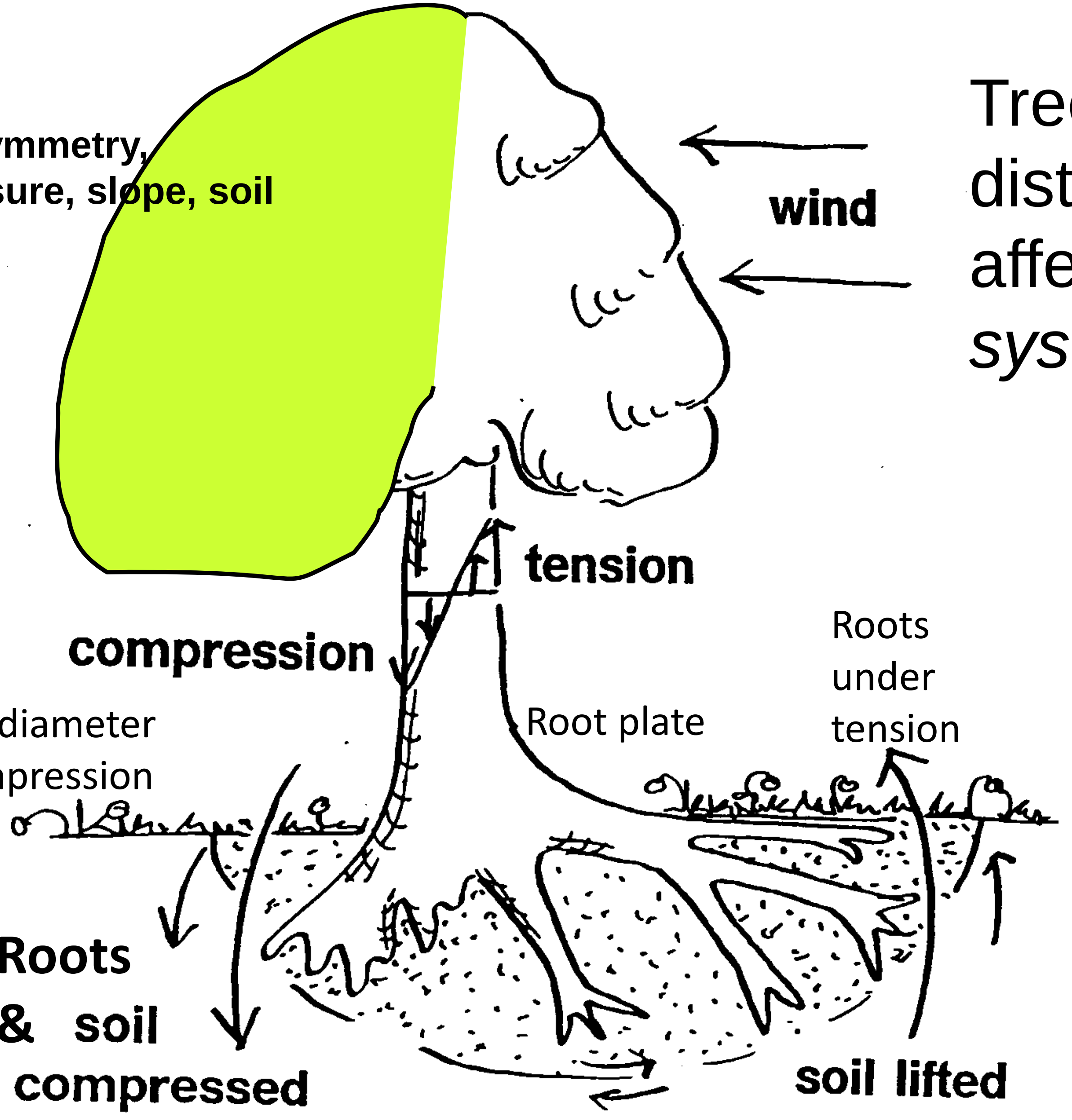
Anchorage is concentrated in two general locations around a tree base

- close to the stem base on the leeward side and focused on several large diameter roots
- farther away from the stem base on the windward side in many, smaller, medium diameter, near-surface roots.

Coder, Kim D. 2010. **Root Strength & Tree Anchorage.** University of Georgia Warnell School of Forestry & Natural Resources monograph publication WSFNR10-19*. Pp.88

Tree Root Biomechanics

Tree weight distribution affects *structural root systems*



-Claus Mattheck

- *More* lateral woody roots on the tension side
- Also, the *direction of growth* of roots on tension vs. compressed sides may differ

Trees (2005) 19: 374–384
DOI 10.1007/s00468-004-0396-x

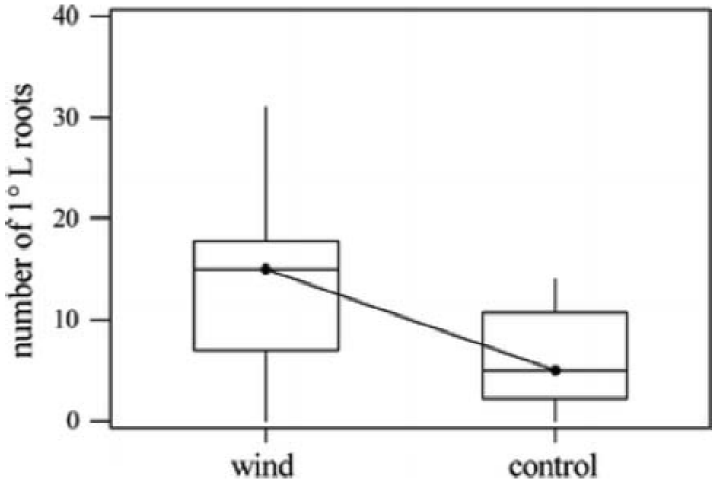
ORIGINAL ARTICLE

Coarse root system

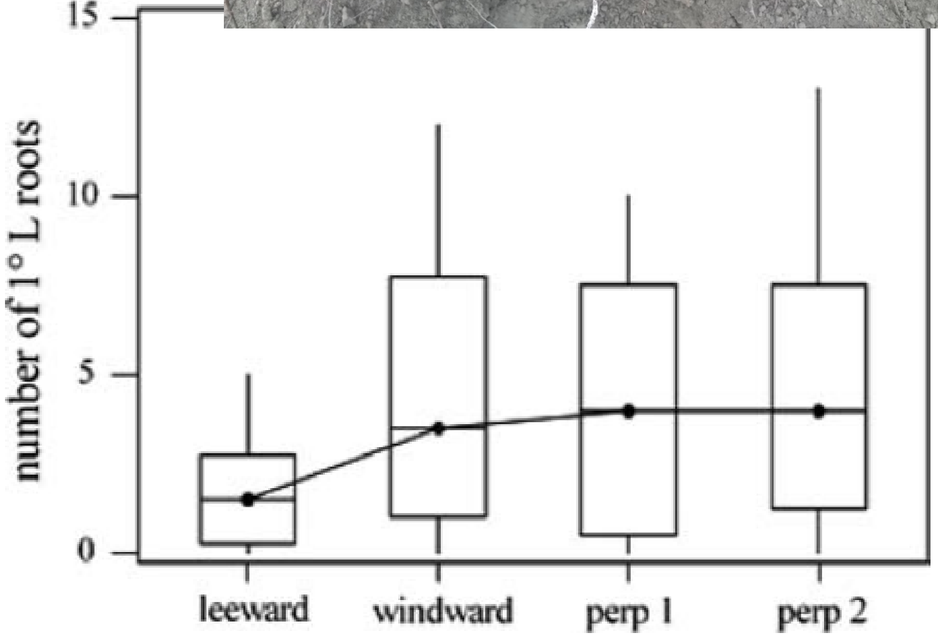
Elisabetta Tamasi · Alexia Stokes · Bruno Lasserre ·
Fréderic Danjon · Stéphane Berthier ·
Thierry Fourcaud · Donato Chiatante

Influence of wind loading on root system development and architecture in oak (*Quercus robur* L.) seedlings.

Number of lateral roots

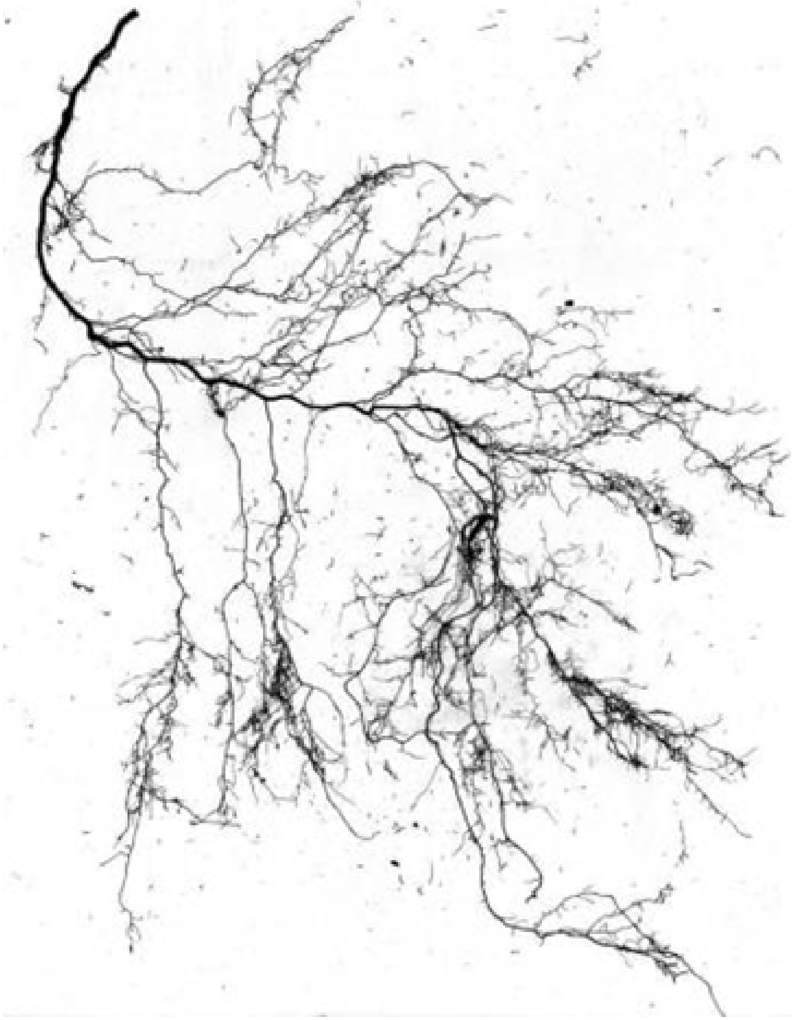


Trees that were <u>allowed to move</u> made more lateral roots and they were located deeper (don't immobilize with a stake)

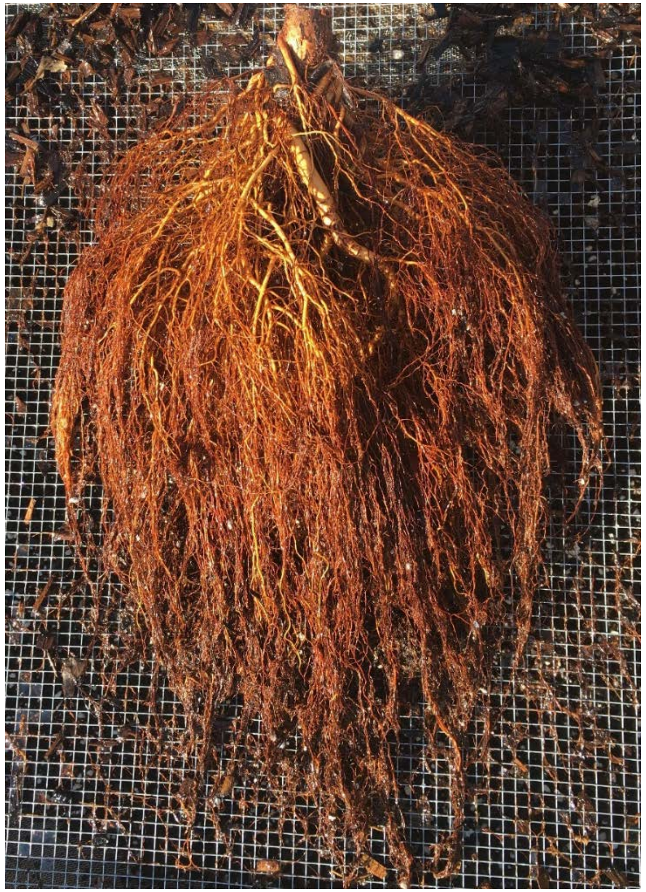


Less lateral roots occur on the leeward side – trees adjust root growth pattern to prevailing wind condition

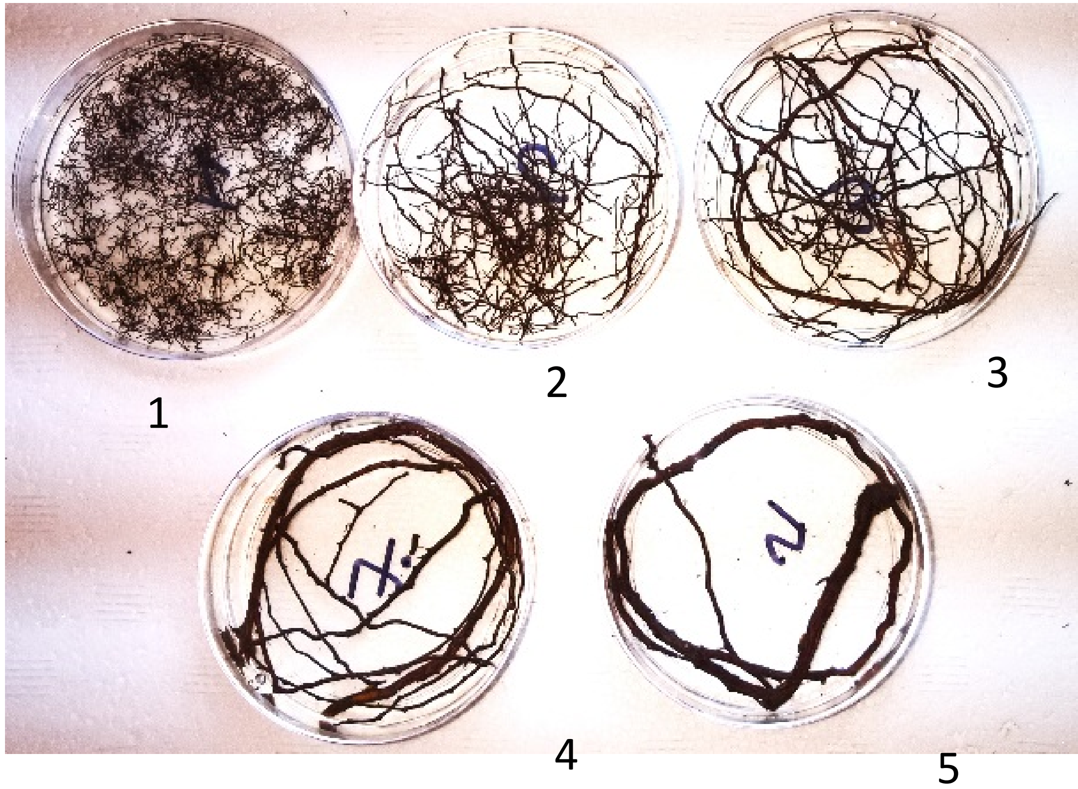
Root systems are optimized for efficient acquisition and transport of water and nutrients



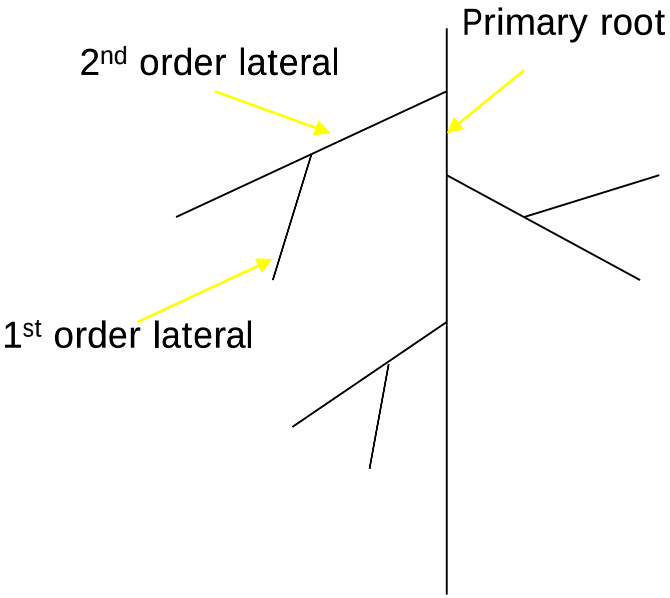
Maximize soil exploration – lots of fine branching

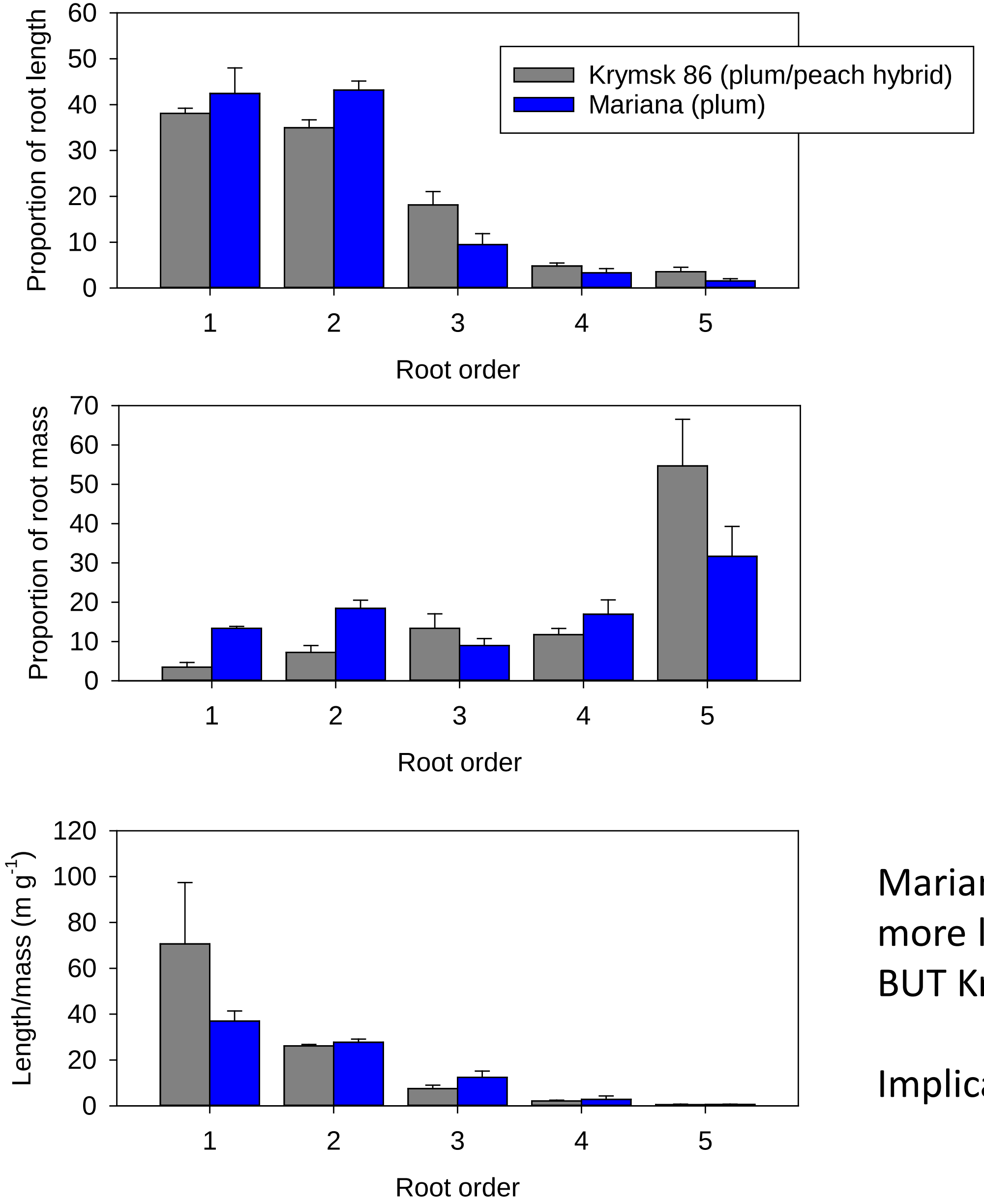


Fine roots – short lived, highly active



Functional classification





Krymsk

Mariana

Mariana has more root length invested in fine roots, while Krymsk has slightly more length, and much more mass, allocated to coarser roots
BUT Krymsk 1st order roots are finer

Implications for nutrient uptake and anchorage (still working on this)

Types of growth

- Indeterminate
  - Growth does not have a pre-set stopping point
  - “Pioneer” roots
  - Generally larger diameter (> 1 mm (0.039 inch) and order (3rd order or larger)
- Determinate
  - Growth stops when a maximum size/length is reached
  - 1st order roots (functional classification)
  - Almond – 0.5 mm (0.020 inch) diameter or smaller
  - Large fraction at 0.1 mm (0.004 inch)

Fine roots proliferate rapidly in response to localized patches of nutrients and/or water

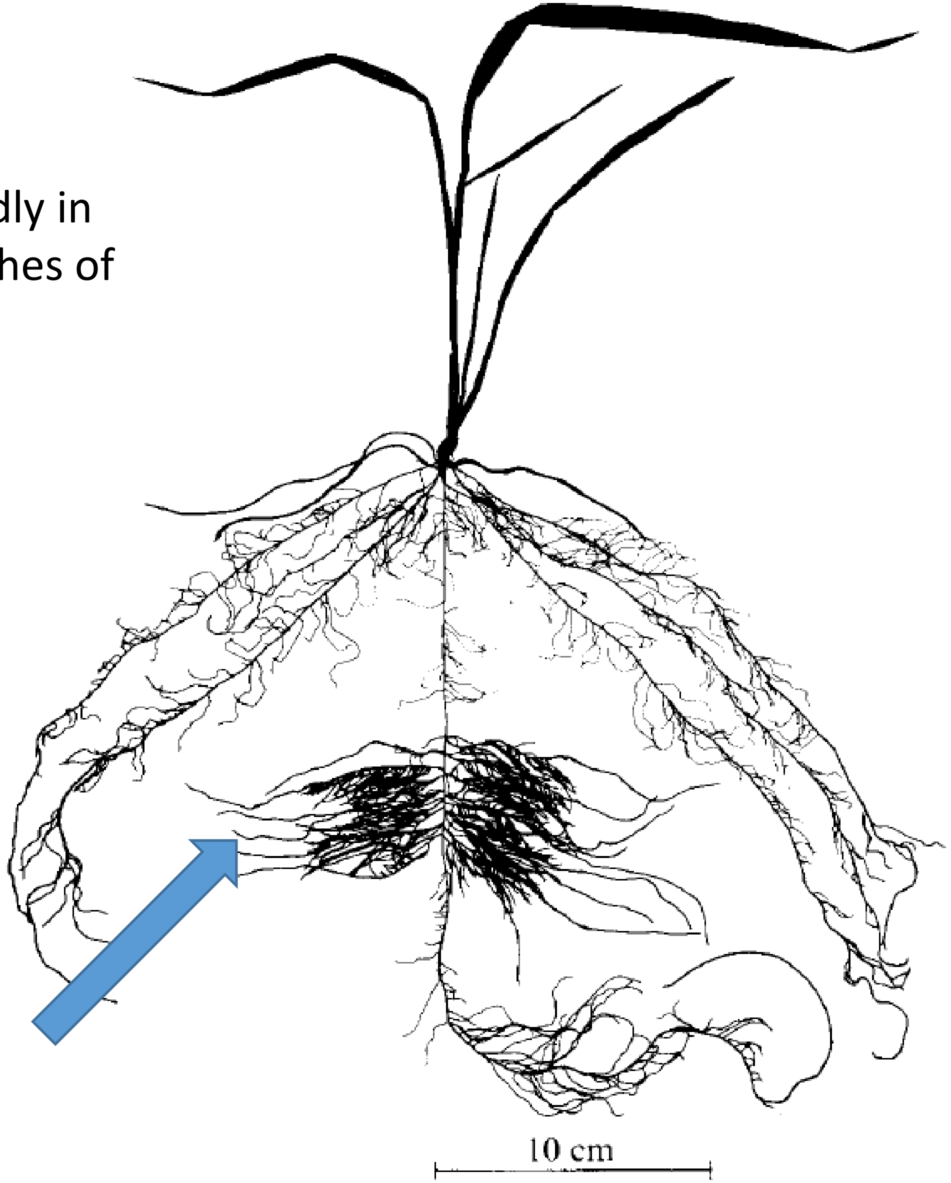
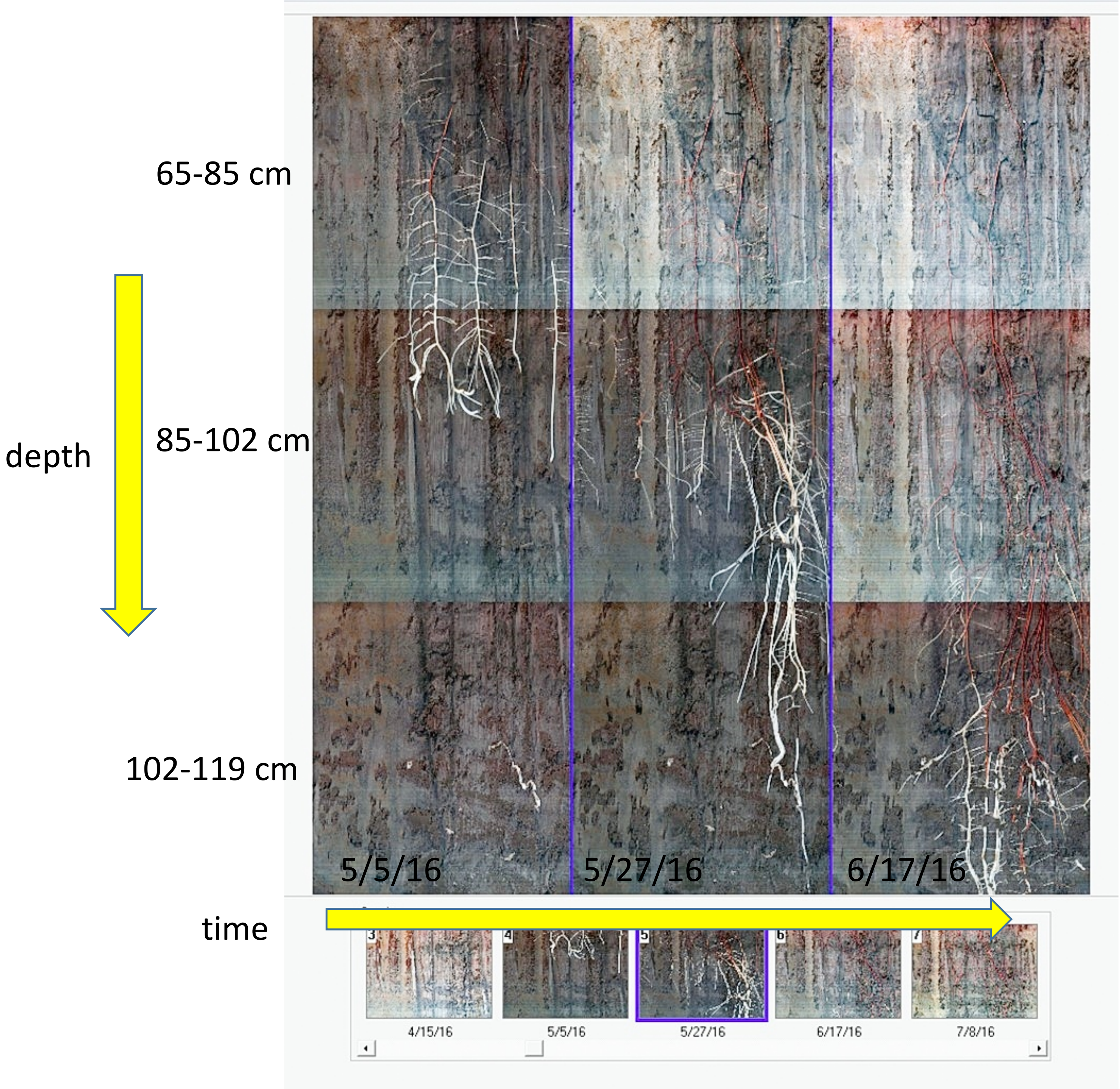


FIG. 1. Effects of a localized supply of 1·0 mM nitrate on root growth in barley. The middle zone of one seminal axis was supplied with nutrient solution containing 1·0 mM nitrate while the remainder received 0·01 mM nitrate. The plant was grown for 20d at 16–18 °C.

Locally enriched zone with nitrate - N

Drew and Saker 1975

Grape fine roots aggregating near subsurface drip

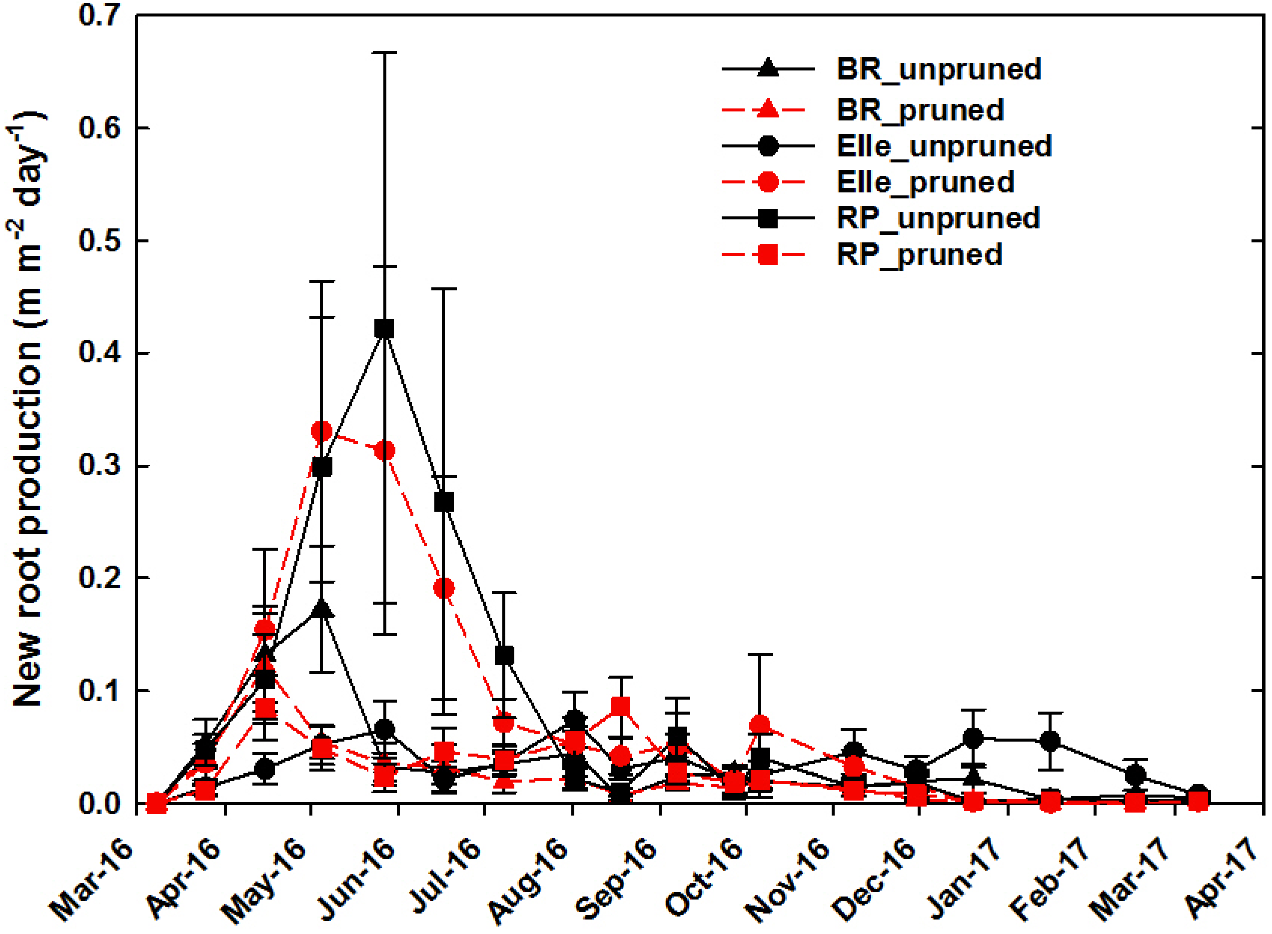


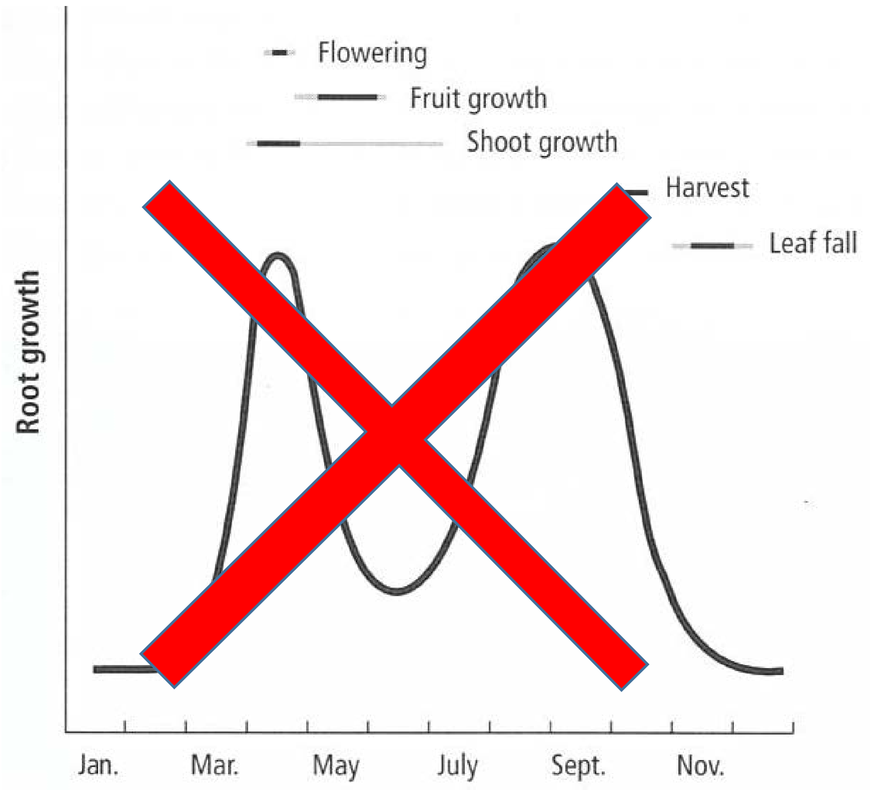
9 images stitched together

Depth – 17 cm increments
Time – 3 weeks apart

Notice progression down tube, branching, and browning

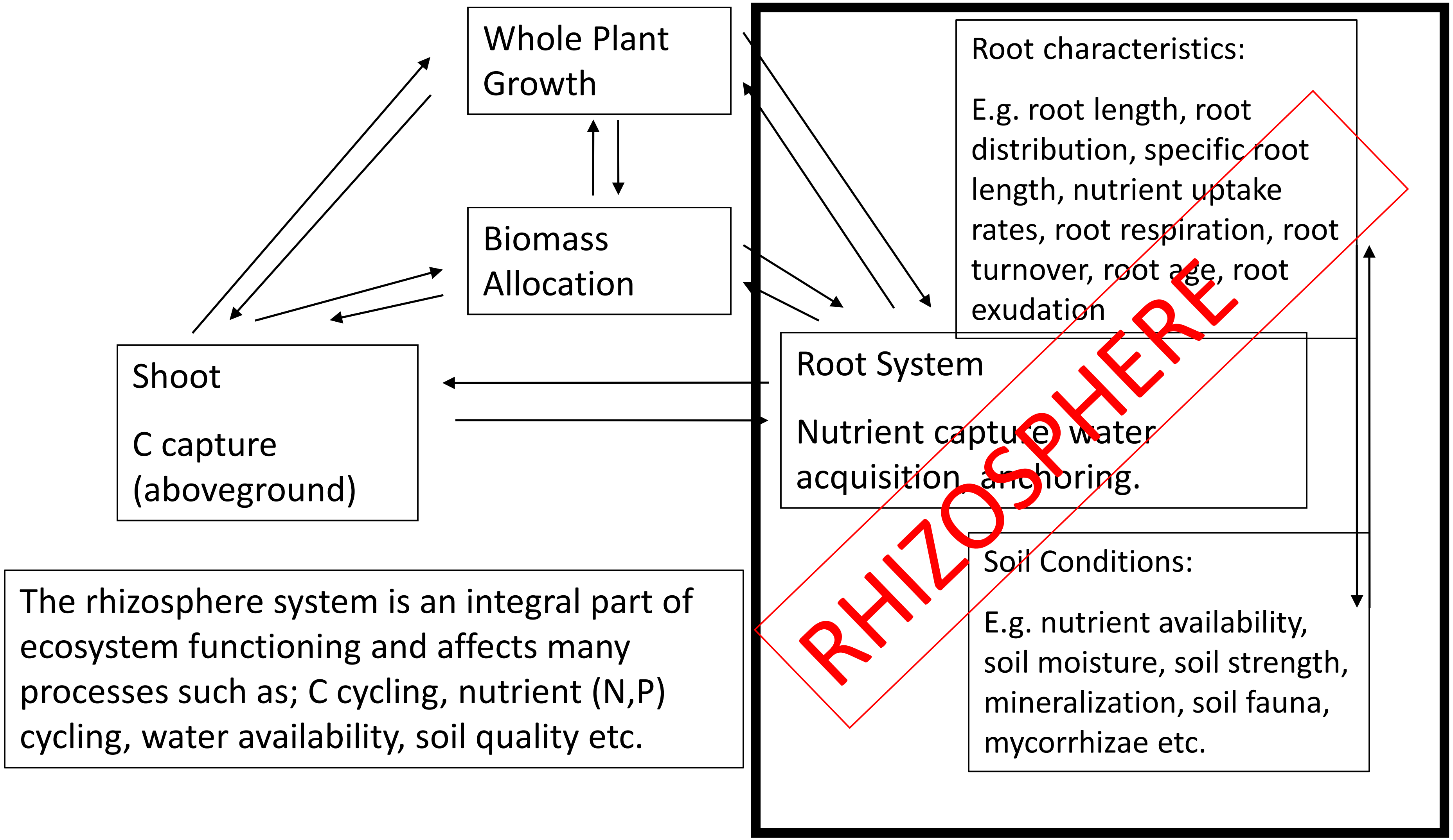
New root production (full irrigation only)





Note absence of Fall peak – should fertilize when you have new (not brown) roots!

Roots & rhizosphere



Rhizosphere

- Zone of soil around roots that is affected by the presence of the roots
  - The zone from which water and nutrient uptake takes place
- Zone with
  - Altered water content (generally more moist) than bulk soil
  - Enhanced microbial activity
    - Stimulated by carbon rich compounds released by roots
    - Direct signaling between plants & microorganism
- Mycorrhizal sphere
  - Expanded zone that includes the soil area influenced by the presence of a root associated mycorrhizal fungus
- Microbes and roots – need oxygen for respiration (oxygen is displaced by water when soil is saturated)

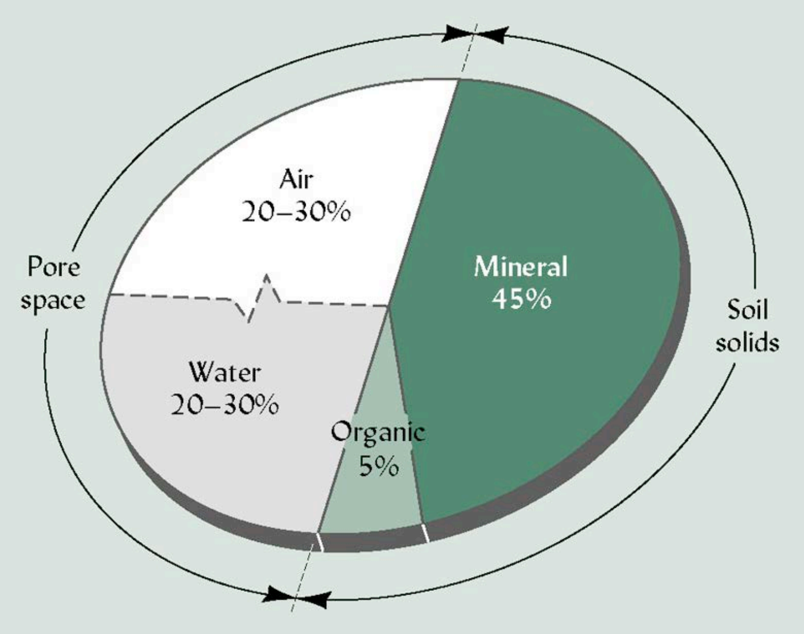
Factors essential for good root development

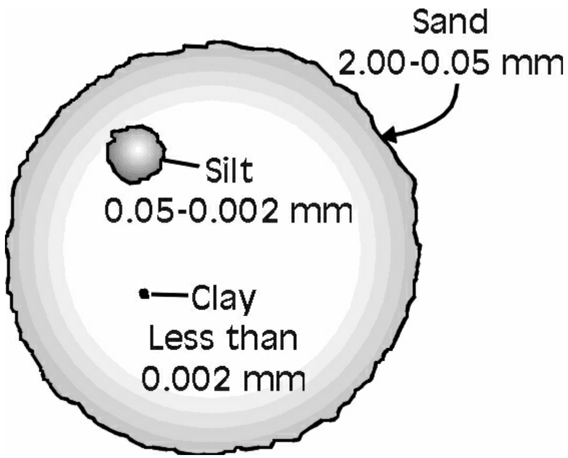
Pore space contains

- Water
- Air/Oxygen

Oxygen diffuses 10,000 times slower through water than through air. Too much water → not enough oxygen to support root function

Ideal soil:





Oxygen is essential for root growth

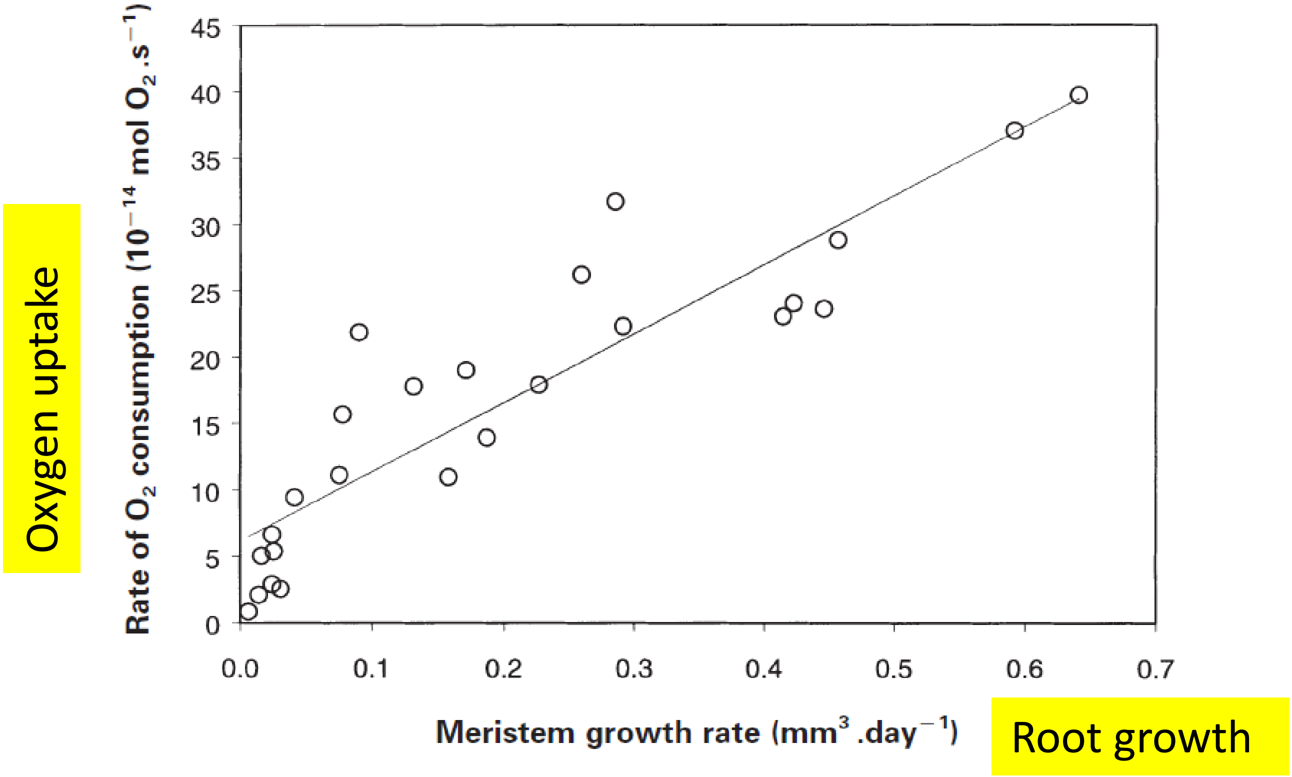


Fig. 5. Relationship between meristem growth, expressed as the volumic rate of tissue production ($mm^3\ d^{-1}$), and O_2 consumption of the meristem (mol $O_2\ s^{-1}$) ($r^2 = 0.90$). The efficiency in root respiration was close to 6.62×10^{-4} mol $O_2\ g^{-1}$ dry matter.

Faster growing roots require more oxygen

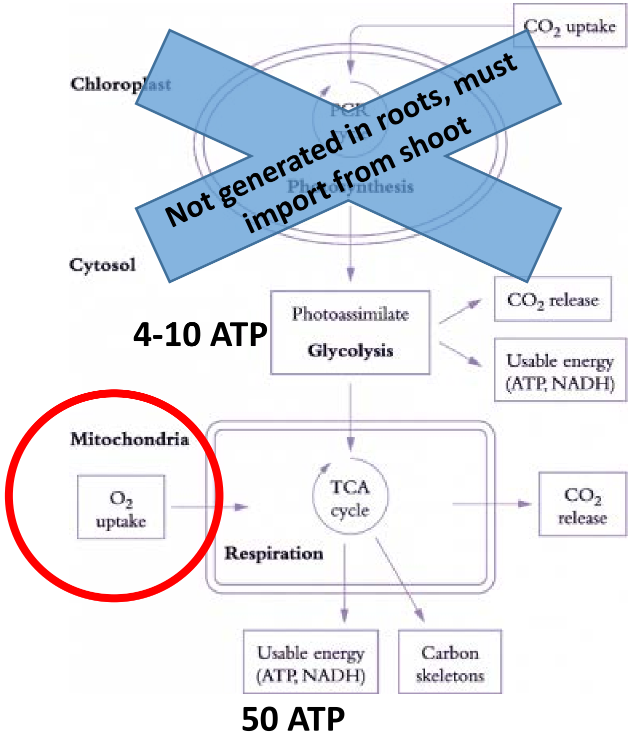
Journal of Experimental Botany, Vol. 51, No. 345, pp. 755–768, April 2000

Journal of Experimental Botany

Mapping meristem respiration of *Prunus persica* (L.) Batsch seedlings: potential respiration of the meristems, O_2 diffusional constraints and combined effects on root growth

L.P.R. Bidel[1], P. Renault[2,4], L. Pagès[3] and L.M. Rivière[1]

Oxygen is essential to generate energy (ATP) in roots



Cellular respiration

Converting to ATP requires O_2

TABLE 11.2
The maximum yield of cytosolic ATP from the complete oxidation of sucrose to CO_2 via aerobic glycolysis and the citric acid cycle

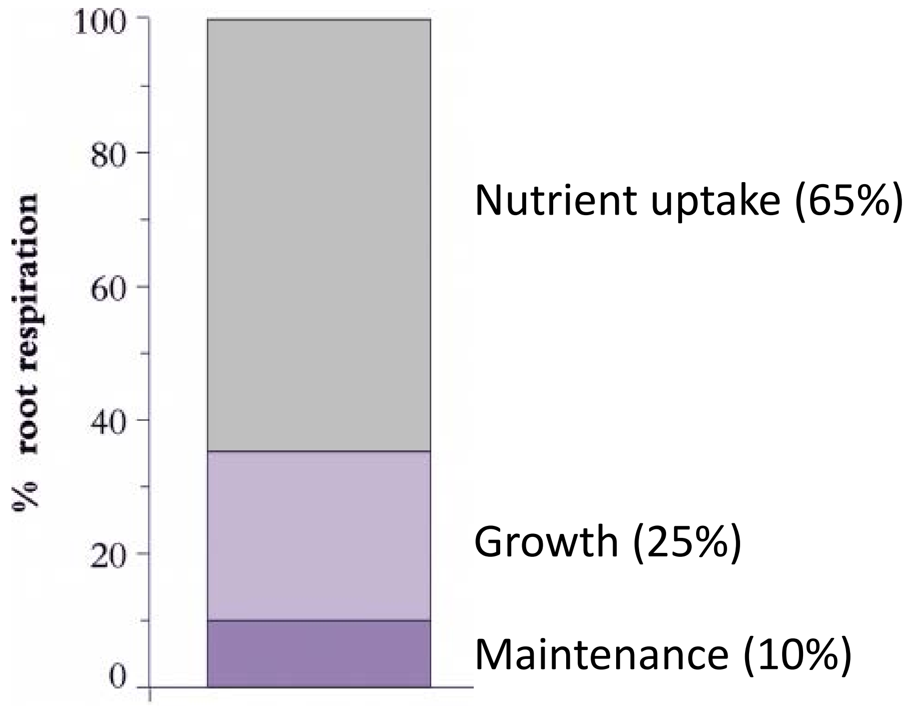
Part reaction	ATP per sucrose[a]
Glycolysis	
4 substrate-level phosphorylations	4
4 NADH	4 × 1.5 = 6
Citric acid cycle	
4 substrate-level phosphorylations	4
4 $FADH_2$	4 × 1.5 = 6
16 NADH	16 × 2.5 = 40
Total	60

Source: Adapted from Brand 1994.
Note: Cytosolic NADH is assumed oxidized by the external NADH dehydrogenase. The nonphosphorylating pathways are assumed not to be engaged.
[a]Calculated using the theoretical ADP/O values from Table 11.1.

***PLANT PHYSIOLOGY*, 5e, Table 11.2** Taiz and Zeiger Plant Physiology

Bottom line: Without O_2, the total ATP yield from one sucrose is 4 ATP instead of 60 ATP → a loss in efficiency of 93%
ATP is used for growth, maintain existing living cells, and nutrient uptake!
Excess water leads to low oxygen, impaired root functioning and ***leaf nutrient deficiency***
- In this case fertilization is not the solution – should reduce watering…..

Most respiratory energy is used for nutrient uptake & growth

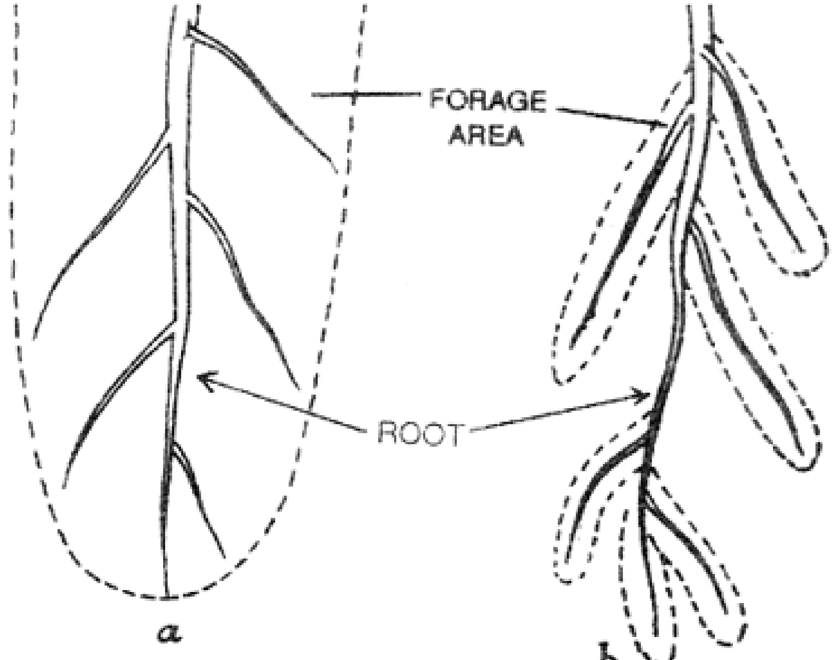


Reproduced from Plants in Action, http://plantsinaction.science.uq.edu.au, published by the Australian Society of Plant Scientists. Chapter 6

Function of fine lateral roots

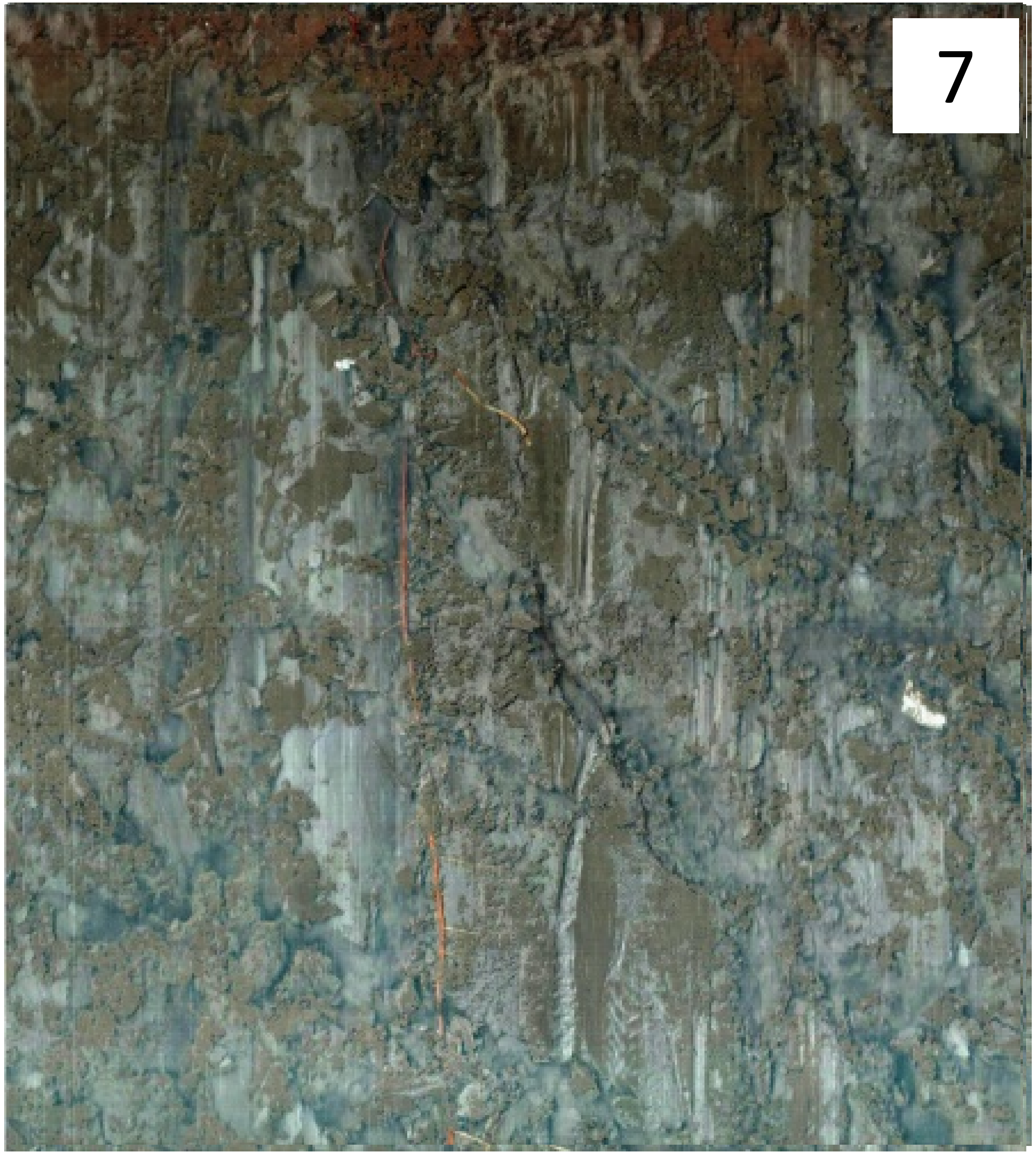
- Acquisition of water & nutrients → expand soil volume explored
- Formation of *nutrient depletion zones* requires <u>constant new growth & exploration</u>

Nitrogen (dissolved in soil water, moves easily)



Forage area for (a) mobile and (b) immobile nutrients

Phosphorus (doesn't diffuse well through soil – sticks to soil particles)



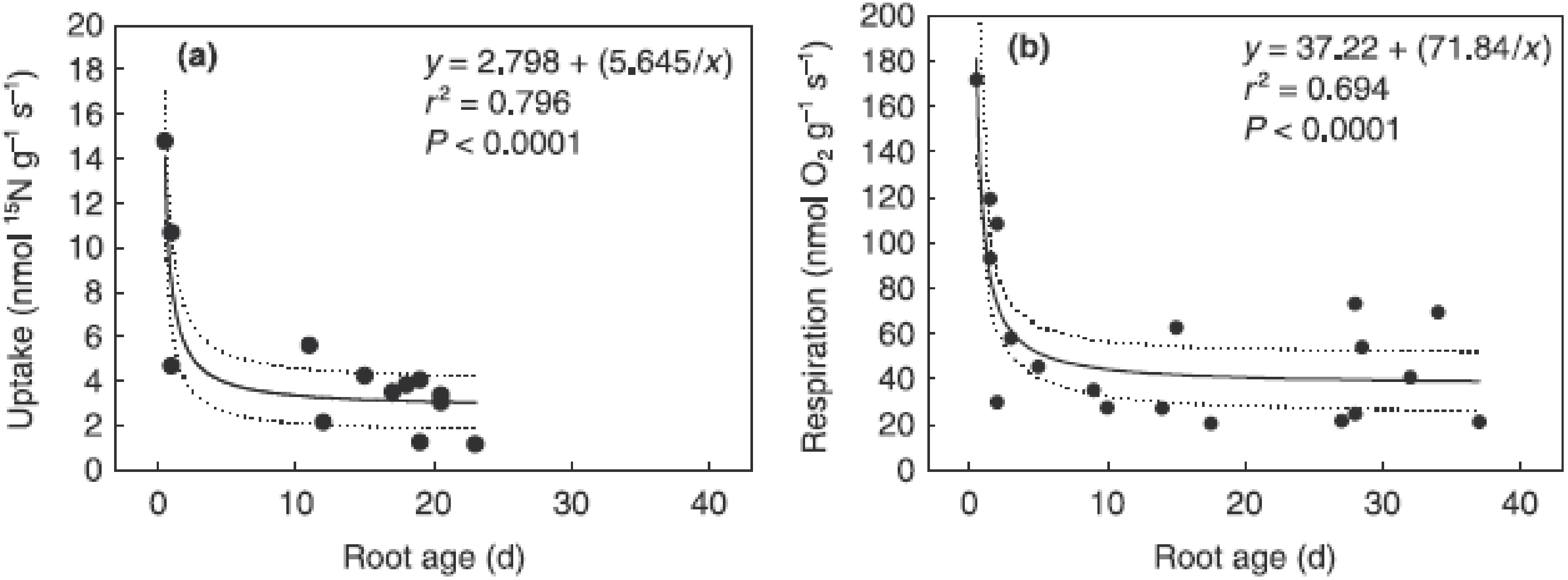
Roots have to continually grow to continue water & nutrient uptake and explore new soil

One week interval

- fine laterals appear and disappear
- higher order root turns brown

Benefit (N uptake)

Metabolic activity (respiration)



Nitrogen uptake

Root browning

Oxygen use

- For container grown grape rootstocks N uptake and respiration declined very rapidly as roots aged
- Repeat in field showed same result

Favorable physical environment for root functioning

Water (requires smaller pores to hold water against gravity)

- Reduces resistance to root growth
- Essential for cell elongation as well as leaf gas exchange and overall plant growth

Oxygen (requires air filled pores – macro-pores, well drained soil)

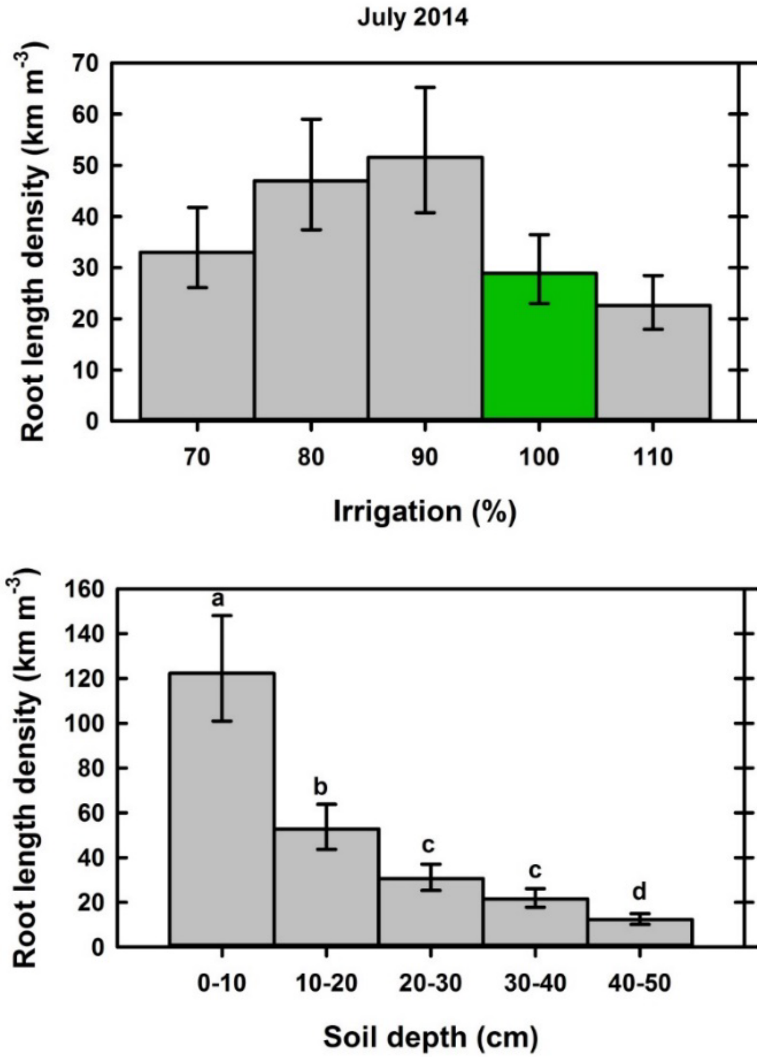
- Energy is used for cellular maintenance, root growth AND nutrient uptake
- Respiration ***in the presence of oxygen*** yields 15 times more energy (ATP)

Nutrients

- Stimulates fine root proliferation and overall plant growth

Balance between providing roots with water, while not reducing oxygen availability to the point it damages the roots. Problems when keeping soils too wet (saturated) too often and/or too long!

At Turlock most fine roots were in the top 10 cm (oxygen, water & nutrients)

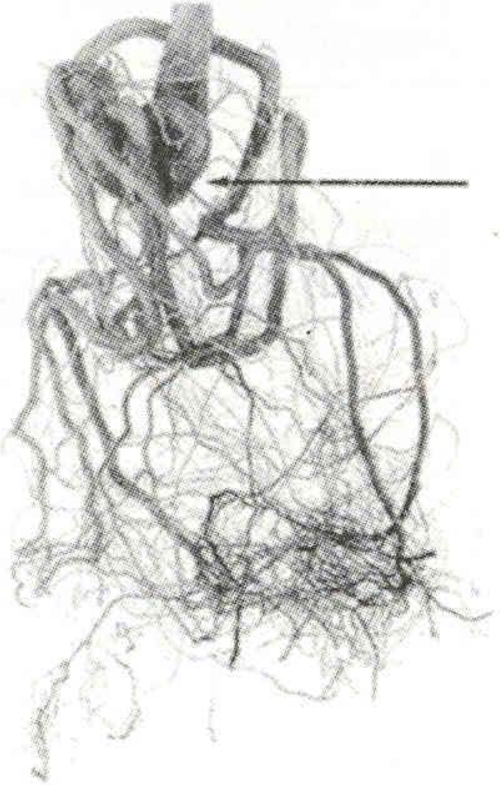


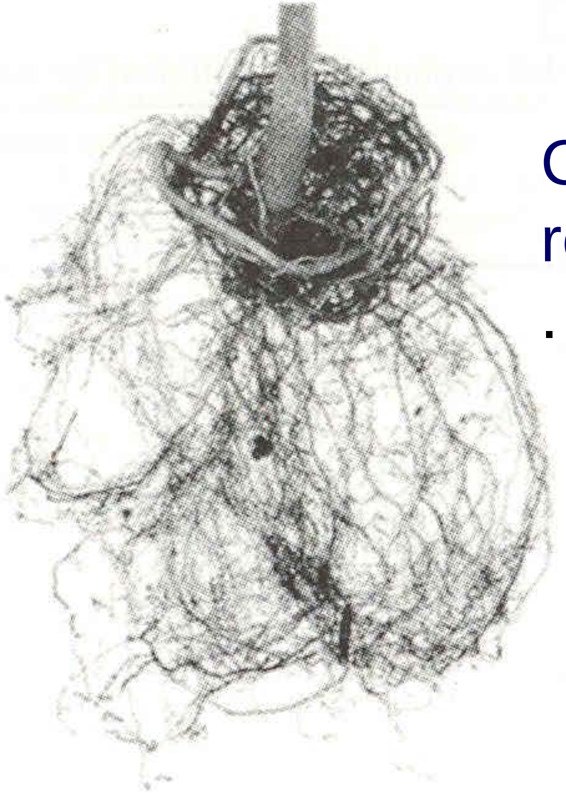
- 20 km per cubic meter = 9.5 mile per cubic yard
- Irrigating slightly below ET yielded the highest standing root length density in July

Many root problems can be avoided by paying attention at planting time!

- Roots *well distributed*
- Roots *free of disease*
- Roots *free of defects, such as:*
  - <u>Kinked roots</u>
    - Sharp bend in the tap root or major structural roots
  - <u>Circling roots</u>
    - Roots growing in a circle around the trunk or other roots

Kinked *and* center circling





Center circling roots

.

Kinked root – “J” root –

Root zones of containerized trees
What happens after planting in the landscape?

1. **Trunk surface zone**

   (problems here are almost impossible to correct)

2. **Center zone**

   (container size; also very difficult to correct)

3. **Peripheral zone**

   (to edges of the container; can be corrected with root pruning)

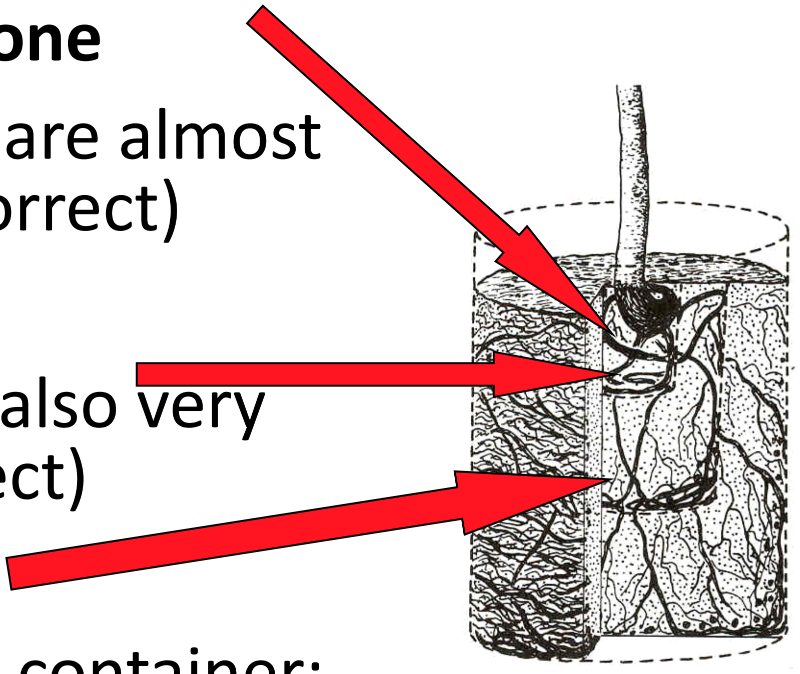
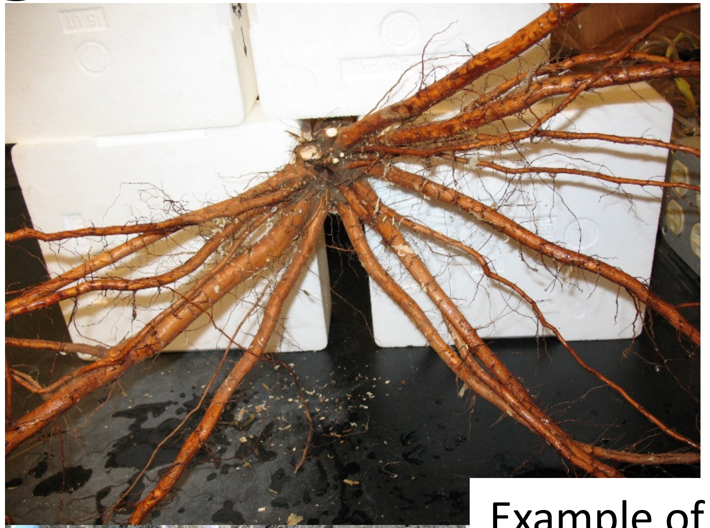


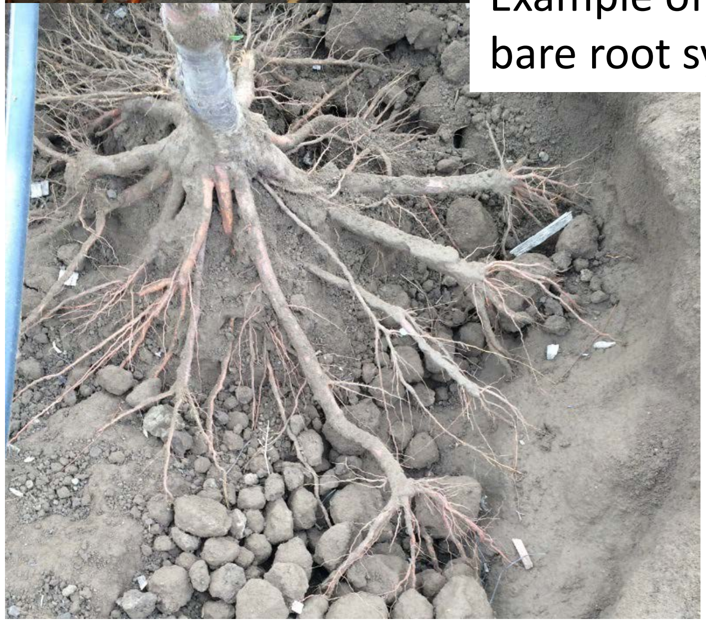
FIGURE 6-8 Kinked and circling roots can occur in different zones of a root ball of 14-l (3.5-gal) or larger; each zone would represent one of the earlier root ball sizes.

Potential impact of girdling roots

Photograph: David Doll

Twisting, girdling or J-roots are undesirable and will likely cause problems

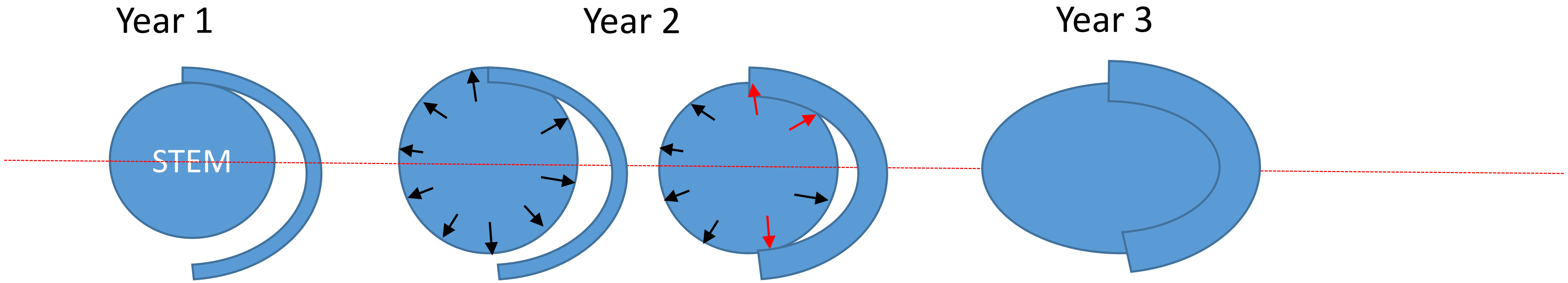




Example of nice bare root system

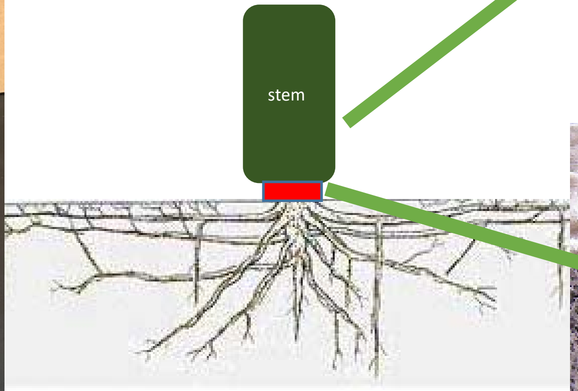
Circling & girdling root issues

- Reduced soil exploration outside the planting hole –> reduced canopy development
- Planting hole may retain more water – majority of circling roots exposed to anoxic conditions → perfect conditions for root rot
- Tree growth & development severely delayed
- Stunted trees receive the same amount of water as big trees and are exposed to saturated conditions longer
- Could grow out of this, but….also long term problem



Root grows in width too

Stem above girdling root will still increase in width, and sometimes even swells, creating a structurally weak “pivot” point for trees to snap



Structural roots & stems both grow in width – restricting stem growth

At planting

- Bare root trees
  - Generally dormant (no transpiration, very little water use)
  - No included growth media – roots placed into same soil as surrounding soil
- Container trees
  - May be active (leaves transpire, higher water use)
  - Included growth media, generally coarser than surrounding fill soil

Result:

- Bare root trees use little water until the tree leafs out while container trees will need very regular irrigation (often already leafed out)
- Coarse container soil will lose water to the surrounding soil → water moves from coarse to fine soil
  - Root ball will dry out faster for container trees due to soil texture difference
  - Covering the root ball with field soil will exacerbate the problem!

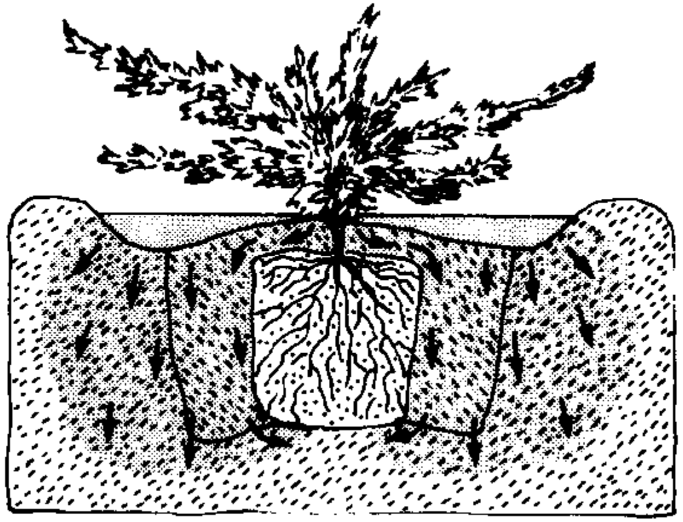
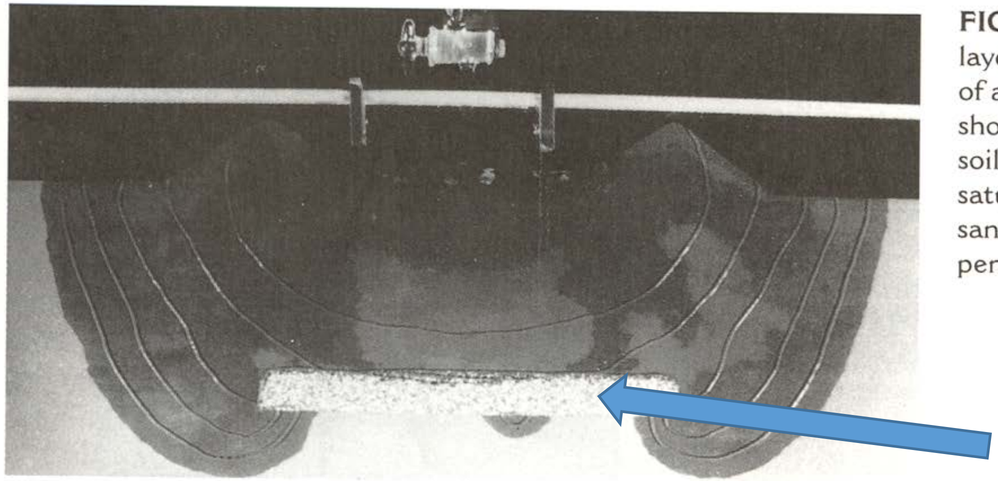


FIGURE 8-11 When a root ball is covered with a layer of soil whose texture is finer than that of the root-ball soil, water will tend to flow around the root ball rather than entering it. The root ball will then be wetted only by water that rises from below.

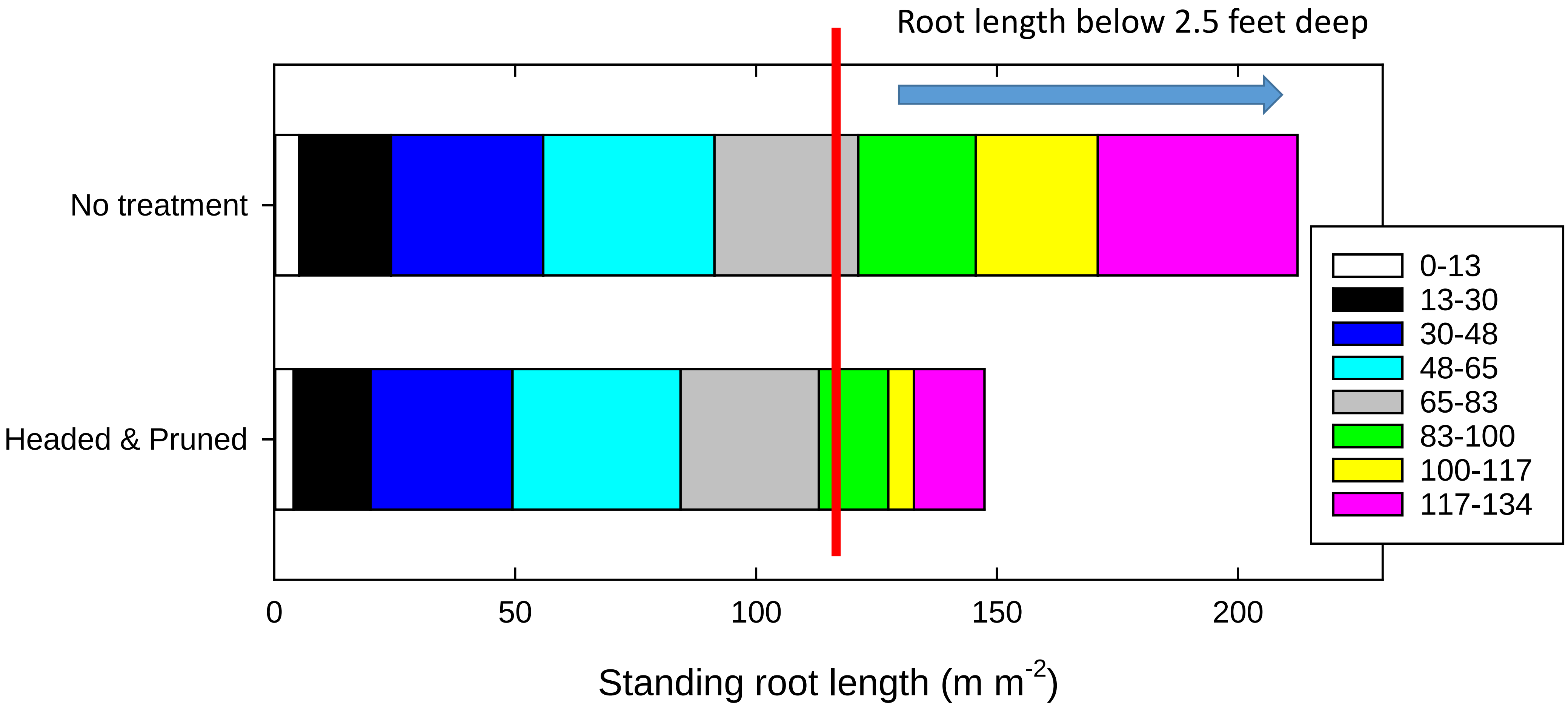
Plant container trees slightly above grade, place drip emitter on the root ball (do not cover with field soil), water frequently



Layer of gravel

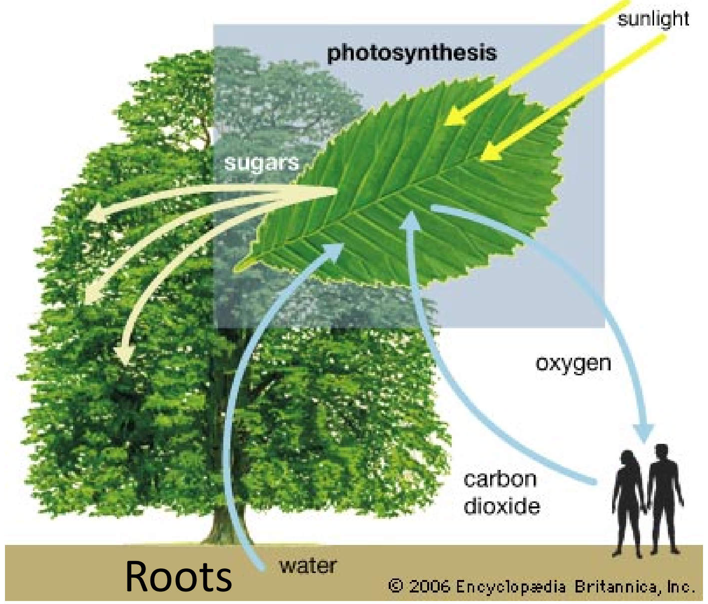
FIGURE 8-6 The fallacy of placing a layer of coarse sand or gravel in the bottom of a planting hole with no drain outlet is shown in the laboratory soil profile. The soil above the sand layer must become saturated before water will move into the sand. Water flowed around the sand before penetrating it.

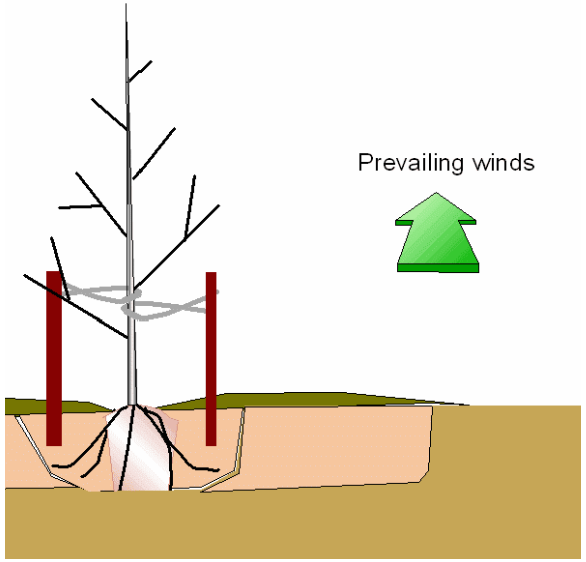
Impact of heading at planting – it reduces deep root production in the first 5 months after planting



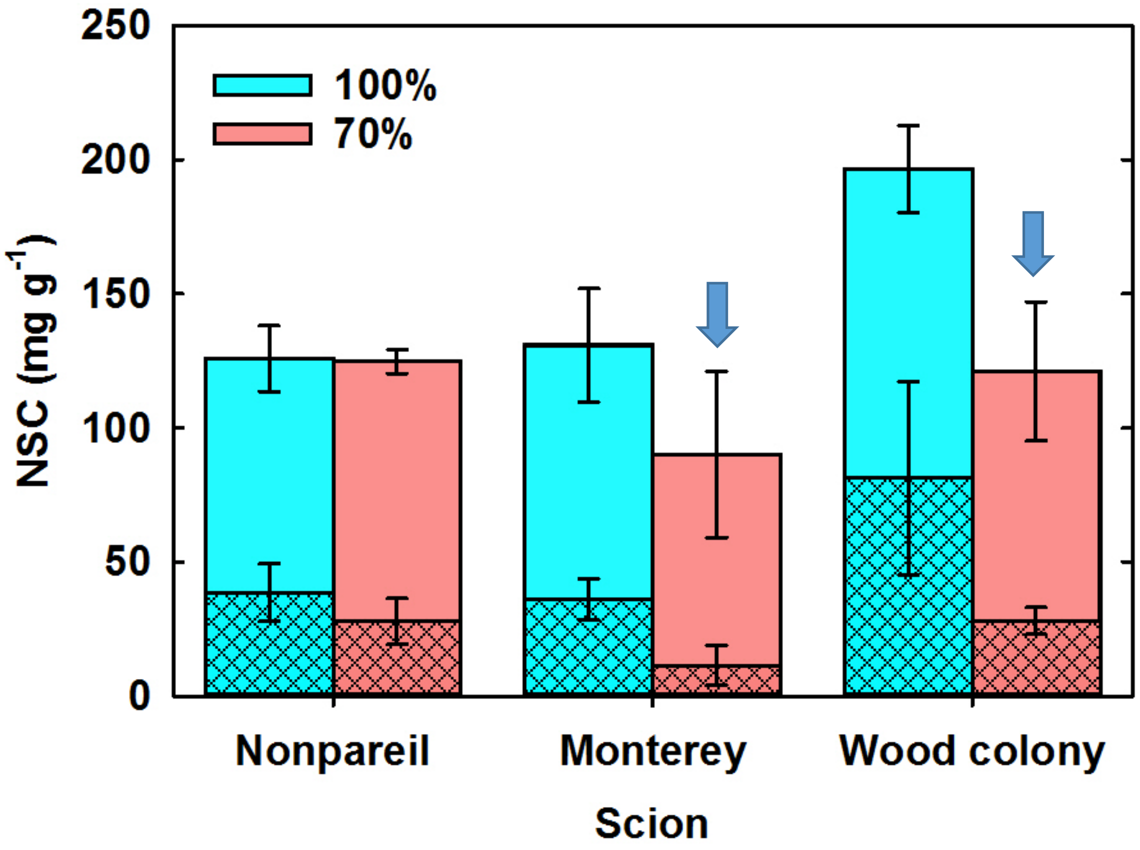
Aboveground factors that affect root growth and function

- Canopy activity – carbohydrate availability for root growth
  - Management (pruning)
  - Solar radiation intercepted
  - Temperature & humidity
- Wind (coarse roots)
  - Tight staking prevents good root development which leads to poor anchorage– trees must be allowed to move
  - Tie loosely at lowest possible height (not at multiple heights)





Impact of irrigation and scion on carbohydrate reserves in fine roots (Krymsk 86)



When receiving adequate irrigation, fine roots of Krymsk 86 with Wood Colony as the scion had the greatest amount of starch and sugars (NSC)

Fine roots of Krymsk 86 with Monterey and Wood Colony as scion reduced starch and sugars when watering was reduced

Strong rootstock x scion interaction which depends on management!

As with heading and staking, what you do aboveground will have effects belowground

Important factors - belowground

- Soil texture (particle composition) and structure – affects soil permeability, water and nutrient transport through the soil to the root, root architecture
- Soil moisture – roots grow where there is soil moisture and nutrients
- Soil oxygen – affects ability of root to function (respire). Generally roots need oxygen concentrations > 10%
- Soil temperature – high soil temps (> 35^{o}C) inhibit root function, 20-25 ^{o}C tends to be optimal
- Soil flora and fauna recycle nutrients and fungal symbiosis may increase root functioning
- Most nutrient availability is greatest at a soil pH between 5.5 – 6.5

Acknowledgements

UCDAVIS
DEPARTMENT OF PLANT SCIENCES
College of Agricultural and Environmental Sciences

- UC Davis pomology farm staff
- Sierra Gold nursery for donating the trees

Funding provided by:
- Almond Board of California
- Department of Plant Sciences at UC Davis

University of California
Agriculture and Natural Resources

Paul Martinez, Bruce Lampinen, Courtney Nichols, Hana You, Xinyu Yao, David Doll, Ken Shackel, Sam Metcalf, Tamara McClung, Loreto Contador, Maciej Zwieniecki

- Primary functions of roots
- • Absorption and transport of water – water is taken up and transport
- along a water potential gradient. (See water transport lectures)
- • Nutrient absorption – nutrients can be taken up actively or passively
- depending on the elements. (See nutrition lectures)
- • Anchorage – this is extremely important and rootstocks can vary
- quite a bit even when grown with a common scion cultivar. This is
- most influenced in a given soil type by root architectural
- characteristics such a number of fine vs. course roots, rooting depth,
- angle of major structural roots, etc.
- • Storage – as noted in previous discussion of CHO storage, dormant
- season CHO concentrations tend to be highest in root tissues and
- can account for as much a 50% of total stored CHO in trees.
- • Conversion or synthesis of growth regulators
- – Auxins
- – Gibberellins
- – Cytokinins
- – Abscisic acid