Plant roots and practical value of plant root symbionts

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„Plant Roots: Biology, Morphology, and Functions"

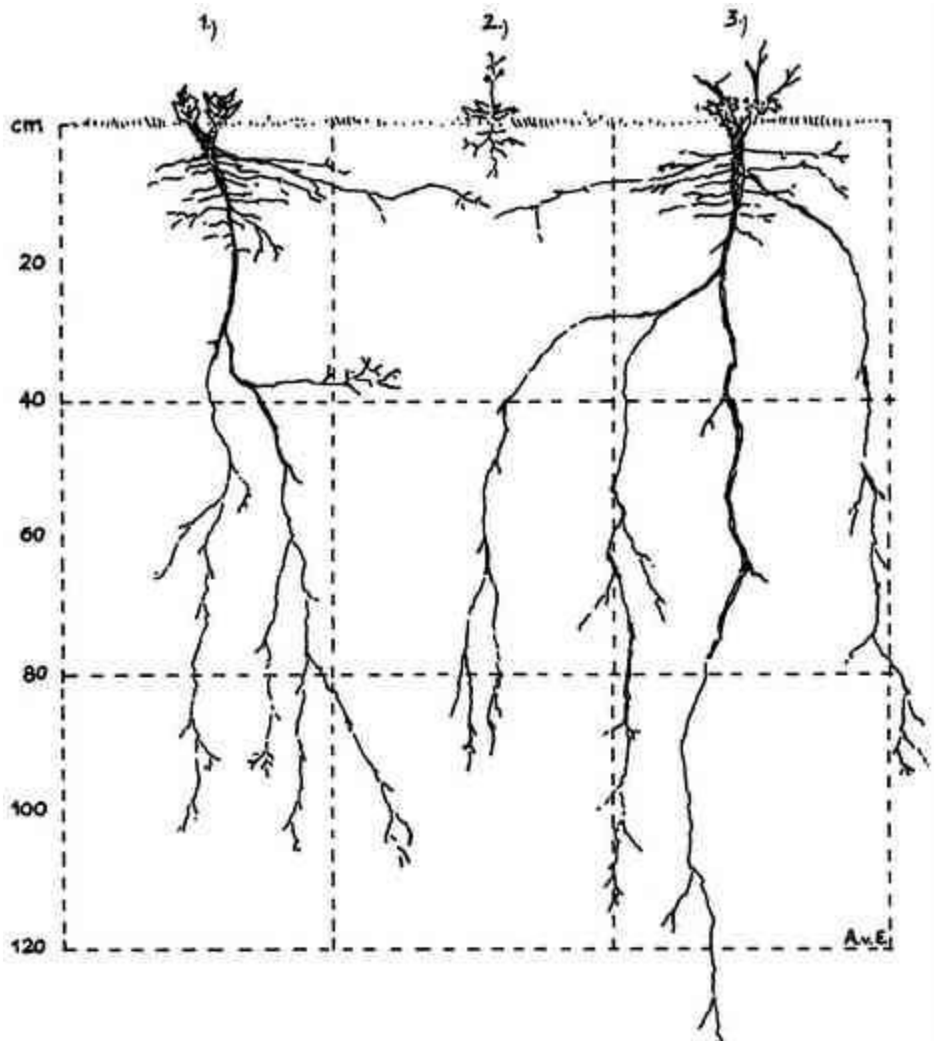
Priv. Doz. Dr. habil Ewald Sieverding
University of Hohenheim
Institut for Plant Production and Agroecology in the Tropics and Subtropics
Garbenstraße 13, Stuttgart-Hohenheim,Germany

D-55578 Sankt Johann, Auf dem Ewiger 15, Germany
sieverdinge@aol.com

What do plant roots do

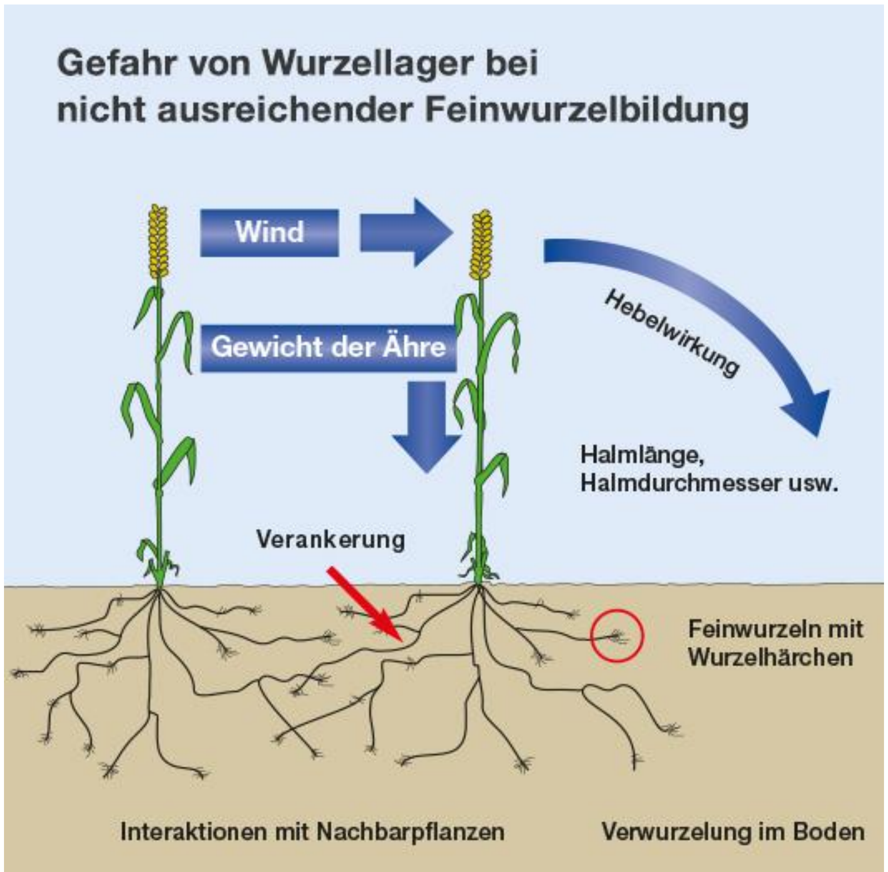
- Fix plants to soil
- Absorb water and nutrients from soil
- Transport water and nutrients to upper parts
- Store assimilates of upper parts (which are remobilized at certain times, or are harvested)
- Exudate components to soil for mineralisation of nutrients
- Act as hosts for symbionts (Rhizobia & Mycorrhiza) and on surface for associations with bacteria and fungi

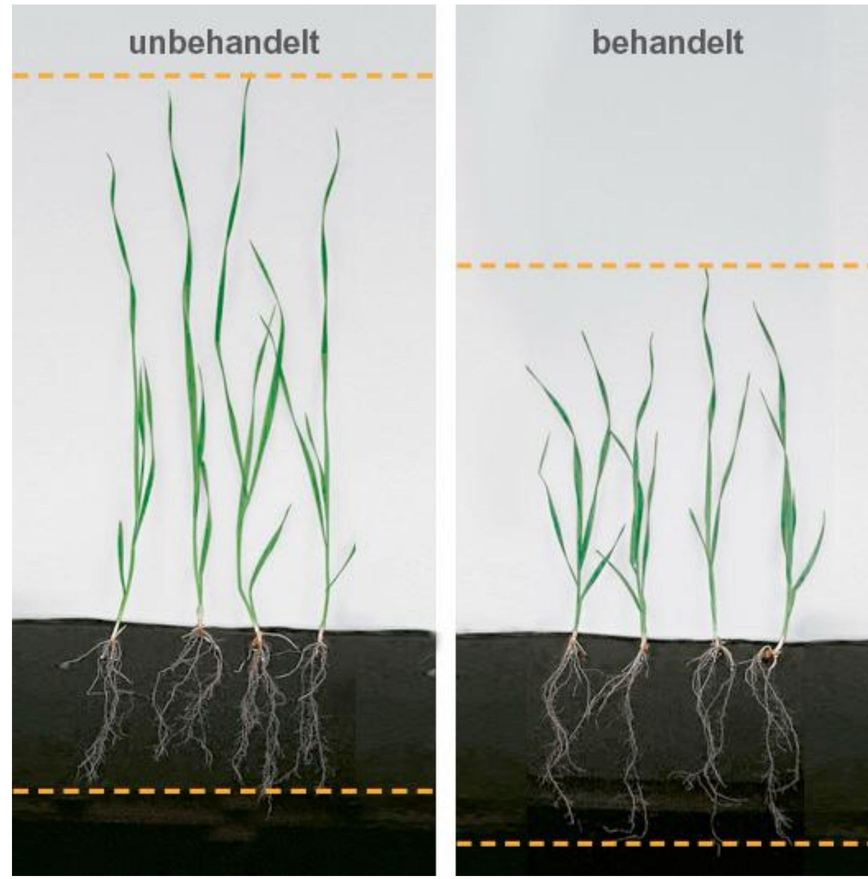
Roots of different plant species can have very different morphologies



Different root morphologies
1) Aufrechter Ziest; stiff hedgenettle (*Stachys recta*)
2) Frühes Hungerblümchen; nailwort (*Erophila verna*)
3) Feld-Beifuß; field mugwort (*Artemisia campestris*)

Roots fix plants in soils (cereals) importance of fine roots

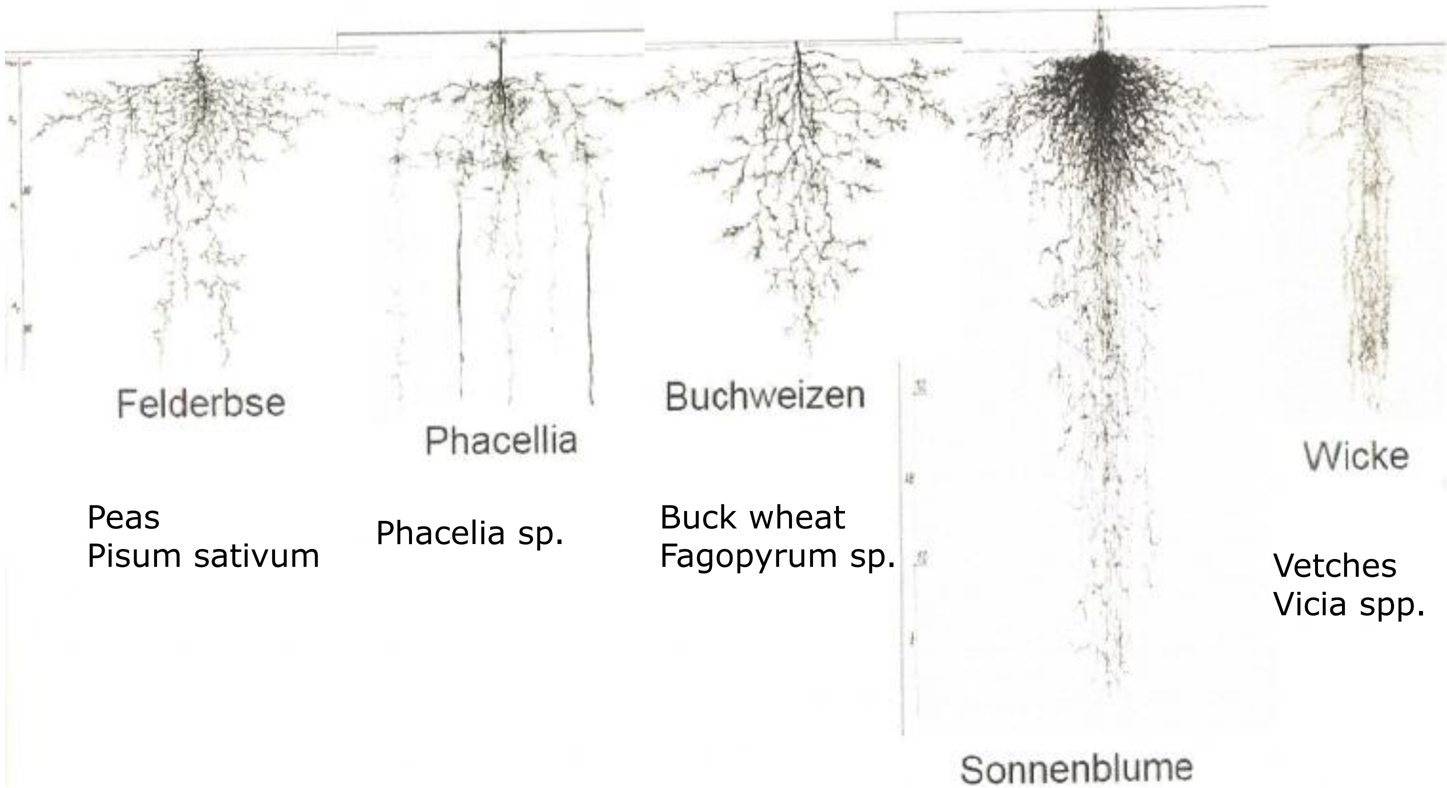




Source: BASF

Deeper and more roots, and less shoot development give more robust crop

Roots of crops grow shallow or deep



Peas
Pisum sativum

Phacelia sp.

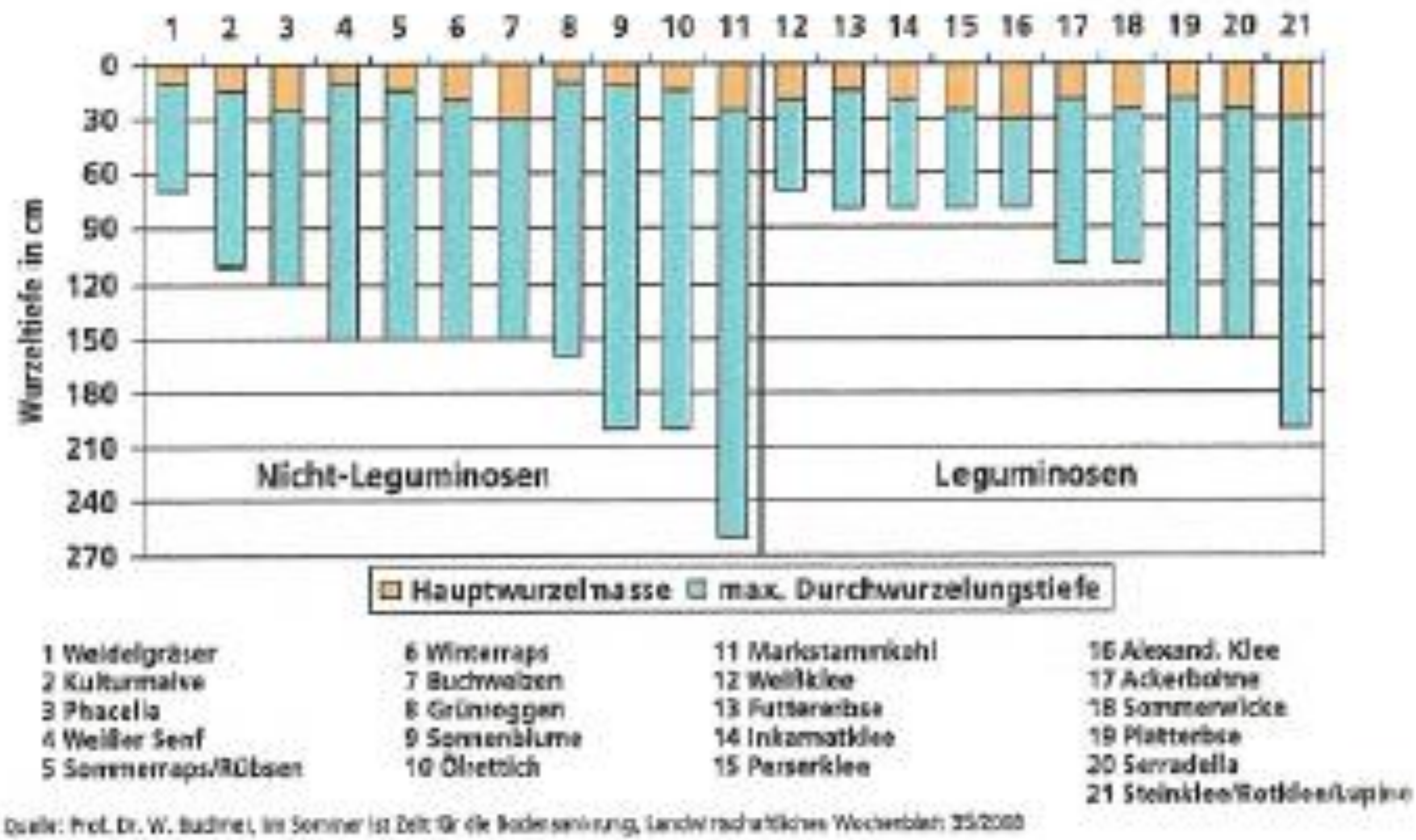
Buck wheat
Fagopyrum sp.

Vetches
Vicia spp.

sunflower
Helianthus annuus

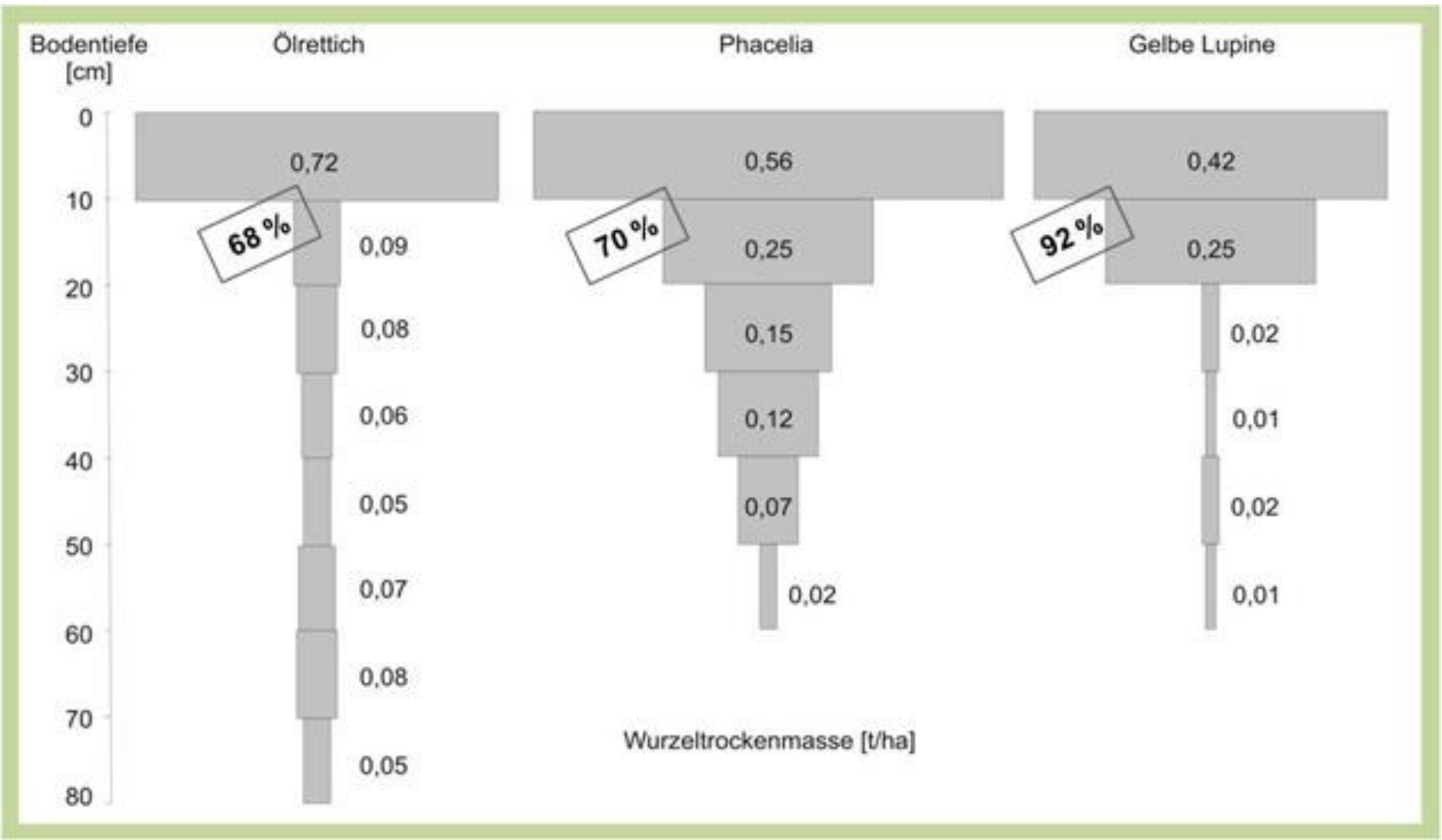
LRA Karlsruhe, Landwirtschaftsamt; Ackerbau-Wasserschutz, Kern

How deep do agronomic plants grow

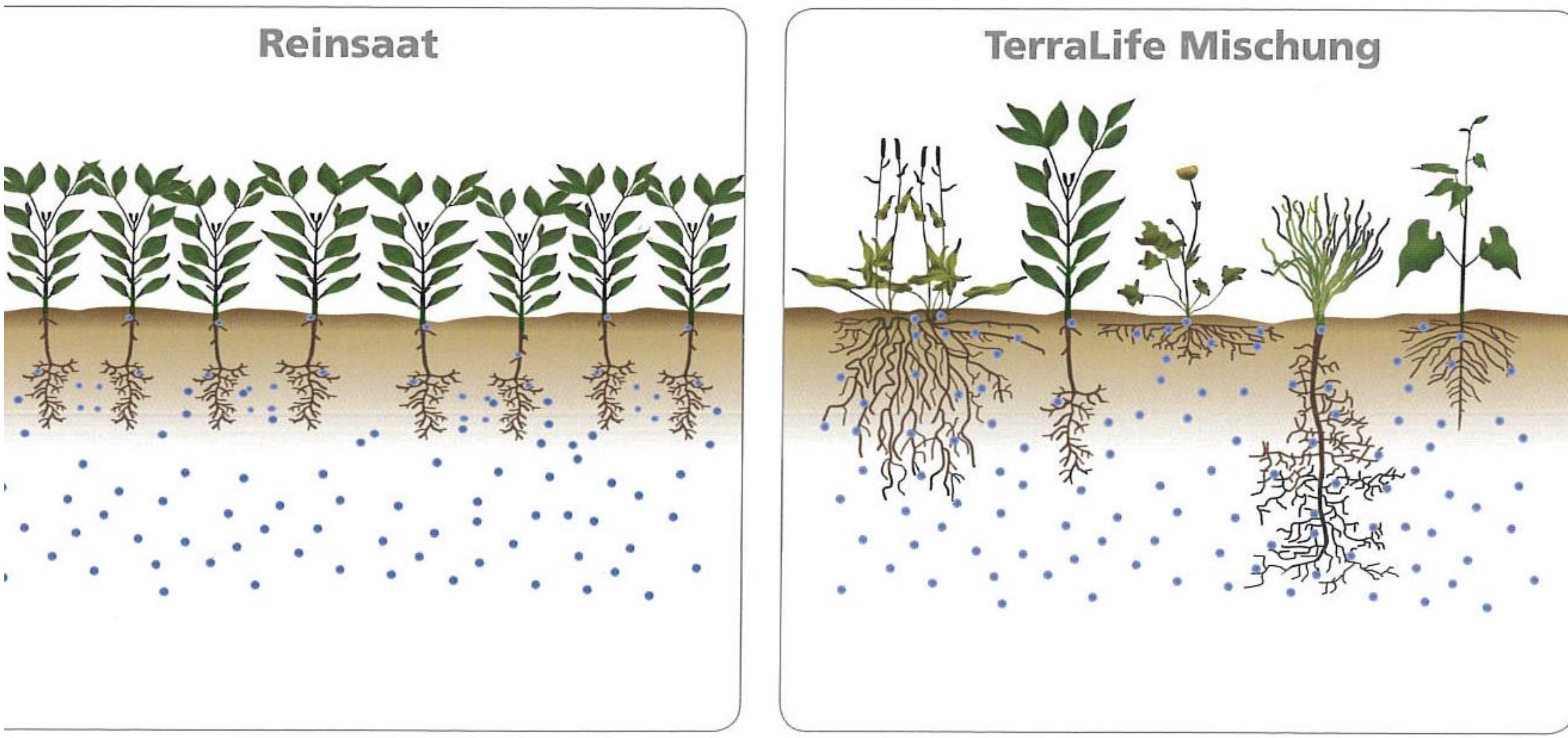


Where is most root biomass

Rhaphanus sativus *Phacelia* *Lupinus luteus*



Mixed crops can better explore soil for nutrients and water



:: DSV, verändert nach Don et. al., 2008 Max Planck Institut, Jena

Mixtures are favoured for intercrops (green manure / greening)

Functional components of roots of some crops

Funktionskomponenten von ausgewählten Zwischenfrüchten

- Trockenkeimer : Bitterlupine, Öllein, Alex., Ramtillkraut, Leindotter, Buchweizen, Peluschke, Serradella
- Tiefwurzler : Bitterlupine, Ölrettich (TR), Öllein, Sonnenblume, Alex., So. Wicke, Gelbsenf
- Flachwurzler : Rauhhafer, Ramtillkraut, Buchweizen, Peluschke, Gräser
- Schattengarebildner : Phacelia, Serradella, Ramtillkraut, Sommerwicke, Leindotter
- N- Sammler : Bitterlupine, Serradella, Sommerwicke, Peluschke Kleearten
- Si- Aufschluss : Öllein
- P- Aufschluss : Buchweizen (anorg. geb. P), Phacelia (org. geb. P)
- Allelopathen : Rauhhafer (Kruziferen, Hirse), Weidelgras (Quecke)
- Mykorrhizierer : Sonnenblume, alle Gräser und Legum., Öllein
- Nematodenred. : Rauhhafer, (Ölrettich), (Senf)
- Förder. von Antibiose: Sommerwicke fördert *Bacillus subtiles* => bekämpft *Streptomyces scabies* (Auslöser von K.- Schorf), *Rhizoctonia* solani und andere

What influences root development?

There is are some relationships between availability of nutrients and root development (well known, nothing new)

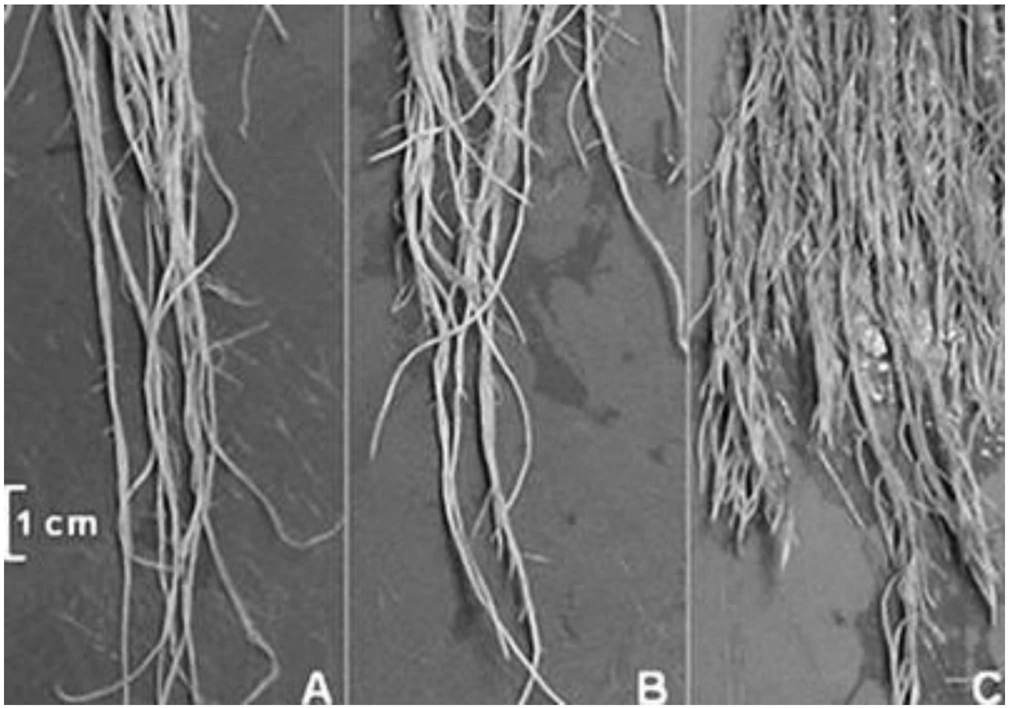
-The lower the nutrient availability, the better the root formation & vice versa

-Phosphate improves root development (- and formation of flowers)

-Light, temperature and water

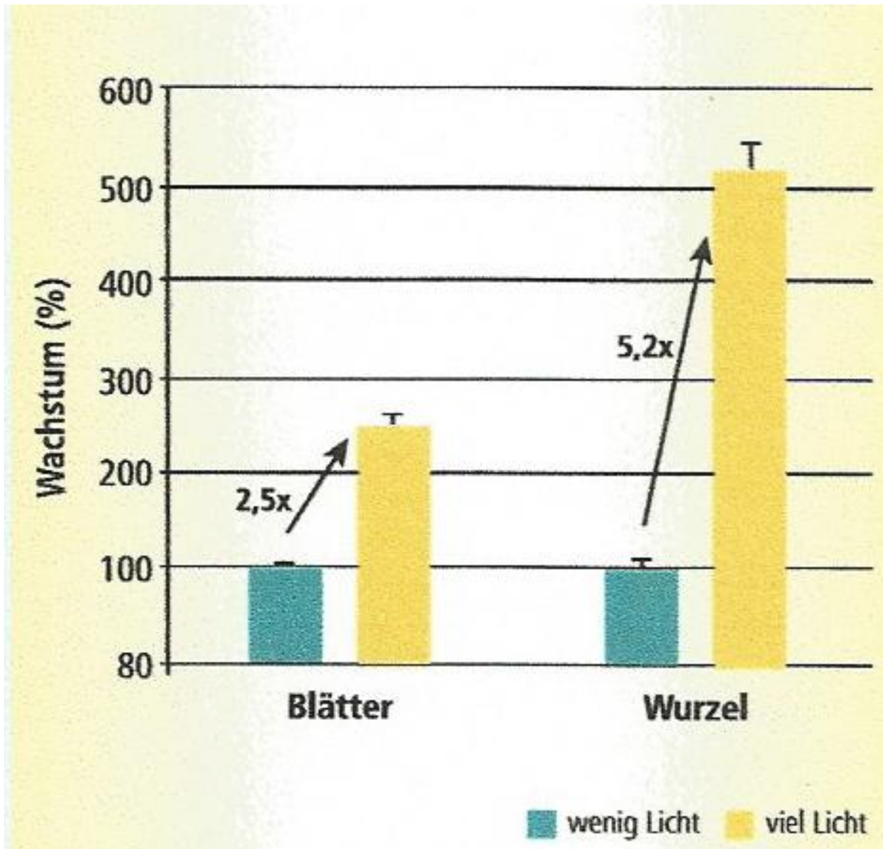
-Airation of soil (compactation)

Phosphate is important for early root development



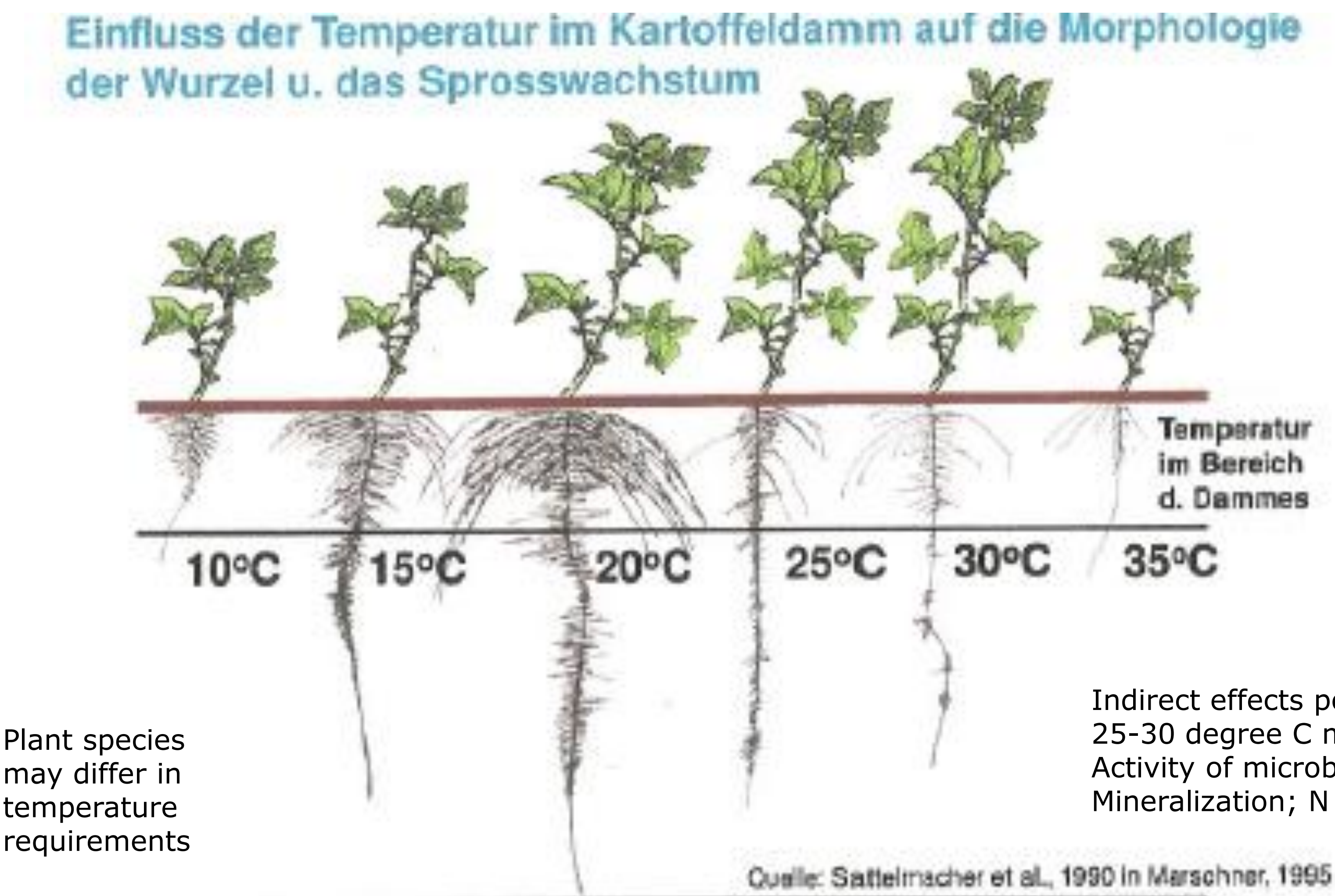
Root development at different P availability (maize)

More light – more roots



Quelle: Forschungszentrum Jülich GmbH

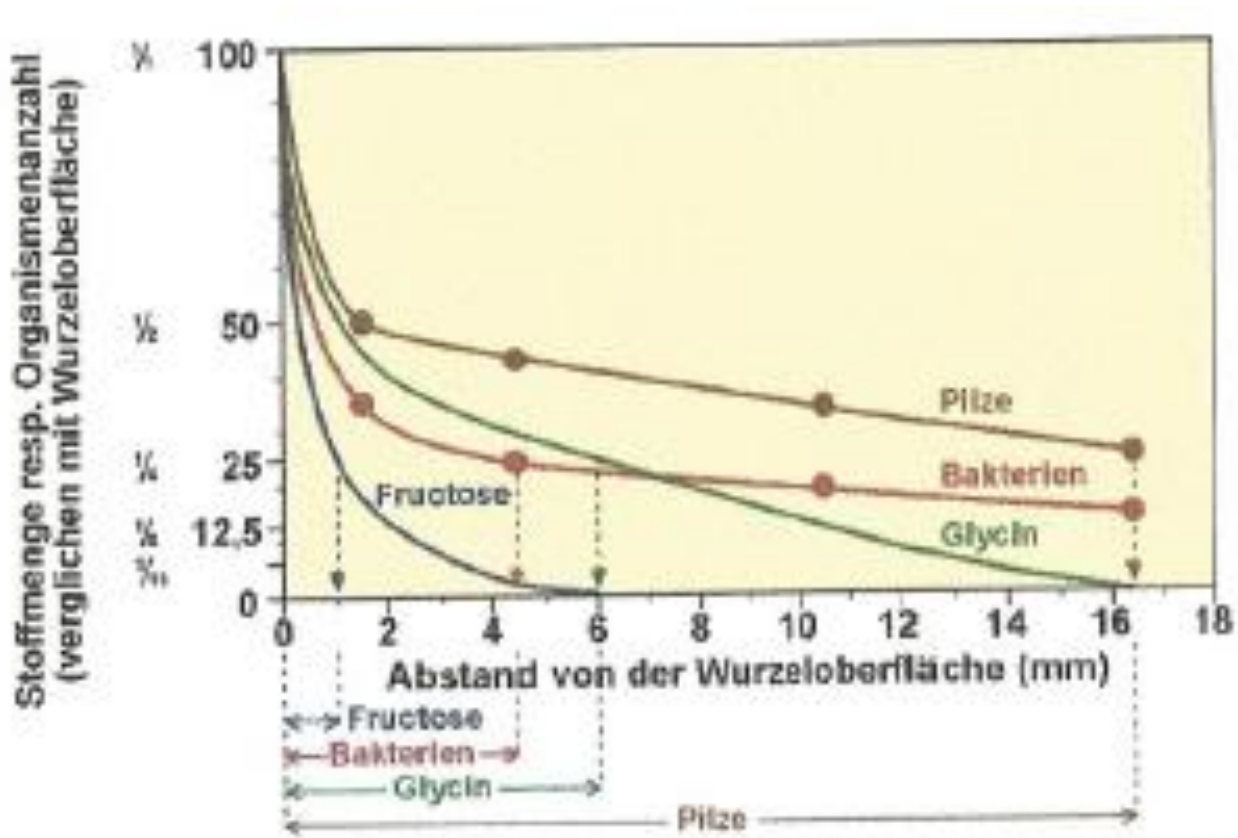
Influence of temperature



Plant species may differ in temperature requirements

Indirect effects possible:
25-30 degree C max.
Activity of microbes,
Mineralization; N availability

Microorganisms in rhizosphere (living on root exudates)



Stoffmengen (Fructose, Glycin) und Organismenanzahl (Bakterien, Pilze) in der Rhizosphäre. Ausgangswert an der Wurzeloberfläche = 100% (1/1)

Quelle: Gisi,1997

Plant Root Symbionts:

- Rhizobia for N_2 fixation
- Mycorrhiza (for nutrient uptake and transport)

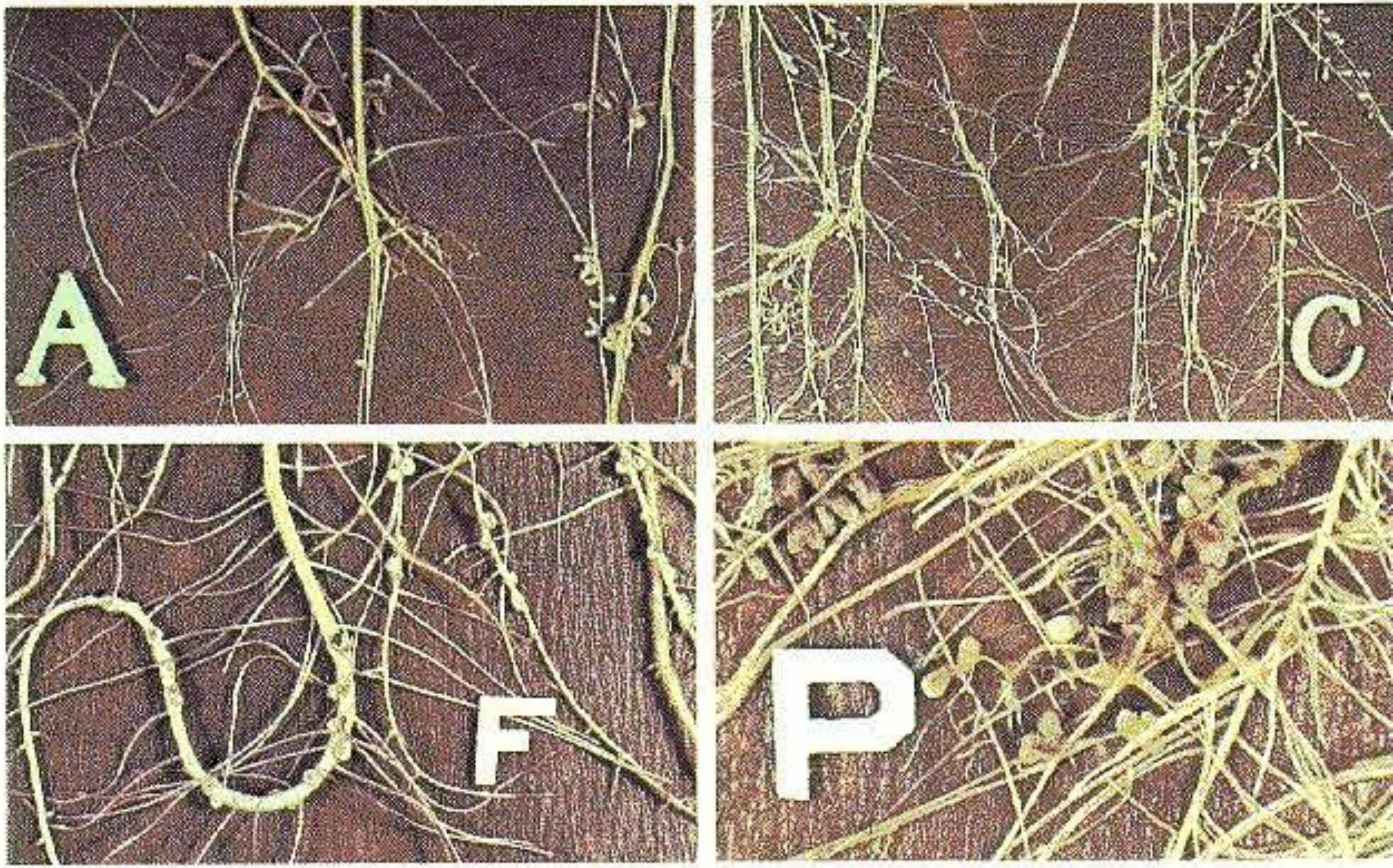
Legumes form symbiosis with Rhizobium in roots and fix air nitrogen








Figure 3. Active Nodules on Roots of Alfalfa (A), Red Clover (C), Fababean (F) and Pea (P)



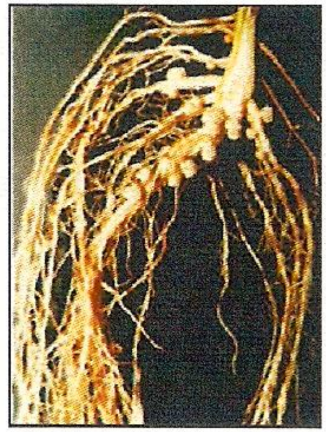
Source: Microbiology Laboratory, Agriculture Canada Research Station, Swift Current

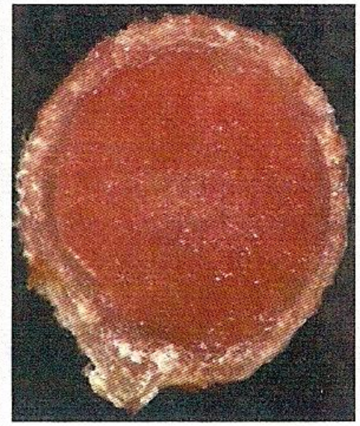
The *Rhizobium*-legume symbiosis

soybean plants

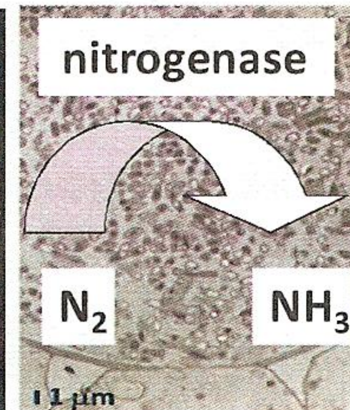
Non-inoculated inoculated

soybean root nodules





bacteroids in infected plant cells



Industrial vs. biological N_2 fixation

Process	10^6 t N year $^{-1}$
Haber-Bosch	100
Biological N_2 fixation	>250

Source: Presentation given by H.M. Fischer. Microbiological Institute, ETH, Zürich, Switzerland, 10 Jan. 2013

Madigan et al., 2012

Gruber and Galloway, Nature, 2008

Selected rhizobial species and their legume hosts

Family	Genus	Species (examples)	Host plant(s)
α-proteobacteria			
Rhizobiaceae	*Rhizobium*	*R. leguminosarum* bv. viciae	*Pisum sativum* (pea)
		R. leguminosarum bv. trifolii	*Trifolium* (clover), *Vicia* (vetch)
		R. etli	*Phaseolus vulgaris* (bean)
	Sinorhizobium (*Ensifer*)	*S.* (*E.*) *meliloti*	*Medicago sativa* (alfalfa)
Phyllobacteriaceae	*Mesorhizobium*	*M. loti*	*Lotus japonicus*
Bradyrhizobiaceae	*Bradyrhizobium*	*B. japonicum*	Glycine max (soybean), mungbean, cowpea, siratro
		B. japonicum ORS278 (photosynthetic, lacks *nodA* and *nodC*	*Aeschynomene spp.*, (root and stem nodules)
Methylobacteriacea	*Methylobacterium*	*M. nodulans*	*Crotalaria* spp.
Xanthobacteraceae	*Azorhizobium*	*A. caulinodans* (genuine diazotroph)	*Sesbania rostrata* (root and stem nodules)
β-proteobacteria			
Burkholderiaceae	*Burkholderia*	*B. phymatum*	*Mimosa* spp., *Phaseolus vulgaris*
	Cupriavidus	*C. taiwanensis*	*Mimosa* ssp.

Source: Presentation given by H.M. Fischer. Microbiological Institute, ETH, Zürich, Switzerland, 10 Jan. 2013

Rhizobia efficacy is strain dependent

Rhizobium strain	*Total N (mg plant^{-1})*
N8	3.7
N5	3.4
S6	3.0
S36	2.5
C100	2.0

Rhizobia inoculants
Legumes seed-inoculation technology

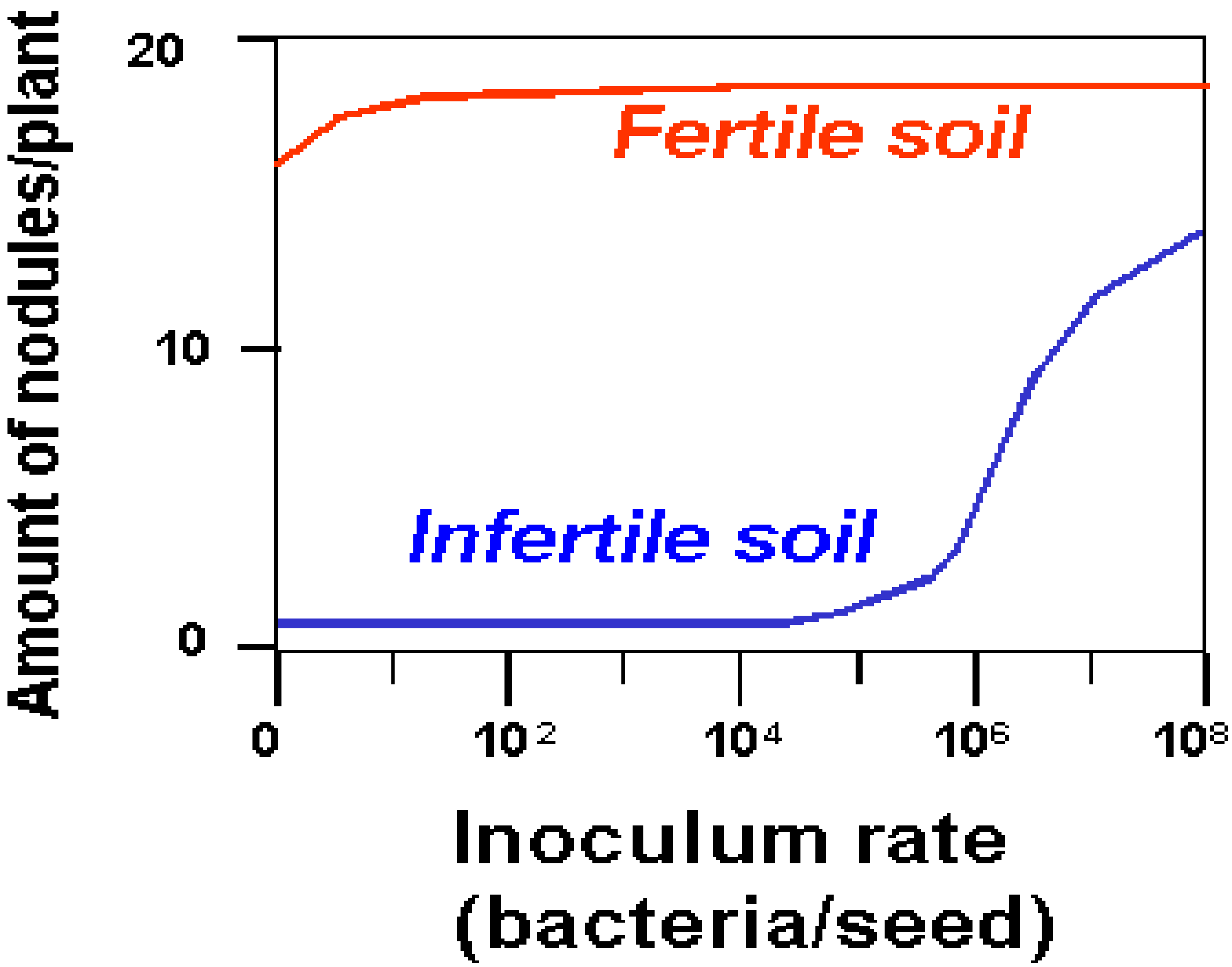
Liquid inoculants

Peat based inoculants

Pellet

Granular peat based inoculum

Commercial products


Amount of nodules/plant
20
10
0
Fertile soil
Infertile soil
0
10 2
10 4
10 6
10 8
Inoculum rate
(bacteria/seed)

Soya grain yield after inoculation with Rhizobium & fertilizing with N

Rhizobium	N/ha	opbr_15%	relatief	eiwit%	N_zaad
coating	**0**	**3797**	**100**	**37.0**	**207**
coating	50	3619	95	35.9	192
coating	100	3583	94	35.4	188
coating	150	3428	90	35.3	176
zonder	0	1629	43	26.6	64
zonder	50	2130	56	26.8	84
zonder	100	2244	59	28.9	96
zonder	150	2593	68	30.2	116
lsd		288		1.2	18

Kg/ha relativ % protein N in seed

PRAKTIJKONDERZOEK PLANT & OMGEVING WAGENINGEN UR

Practical value of Rhizobium-Legume symbiosis

- Effective legume-Rhizobium symbiosis can fix 100-400 kg / ha nitrogen (from air); corresponds to ca 220 – 900 kg Urea
- Fixed N_2 is used for own legume production. Surplus of N_2 for follow crop – N_2 accumulation of 50-200 kg/ha for rotation crop possible
- Legume-Rhizobium symbiosis is sensitive to mineral nitrogen fertilization at planting; it is not recommended to add any Nitrogen when inoculating with Rhizobium
- Effective symbiosis needs phosphate (in fertile soils P is biologically provided by arbuscular mycorrhiza) & special micro-nutrients (Mo, Co, Fe)

Plant Root Symbionts:

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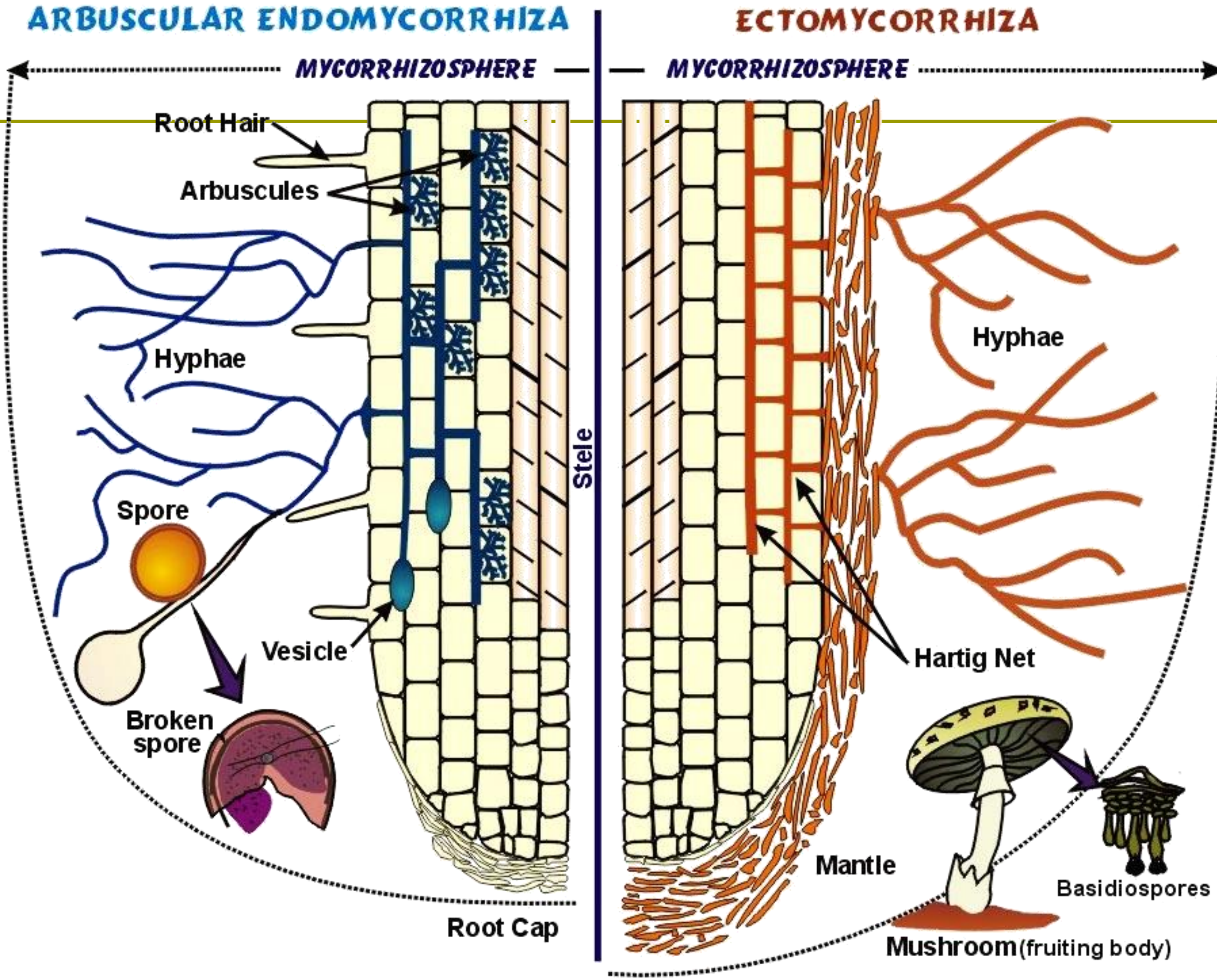
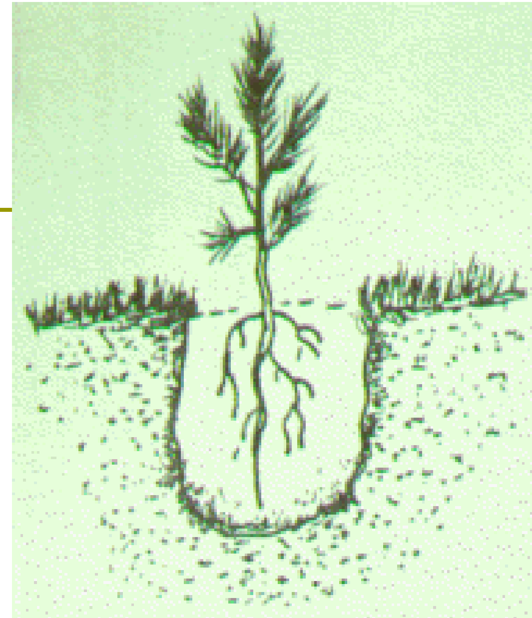
Mycorrhizas – mutualistic symbioses



Ectomycorrhizal fungi (about 5000):
Most are Basidiomycetes;
also some Ascomycetes (truffles);
Zygomycetes (ectendo = Endogone)

Lactarius (left) and Boletus (right)

About 2000 plant species form ectomycorrhiza, mainly trees: Pinaceae, Cupressaceae, Fagaceae, Betulaceae, Salicaceae, Dipterocarpoideae, Myrtaceae, also Eucalyptus species
- All are of obligate mycotrophic character



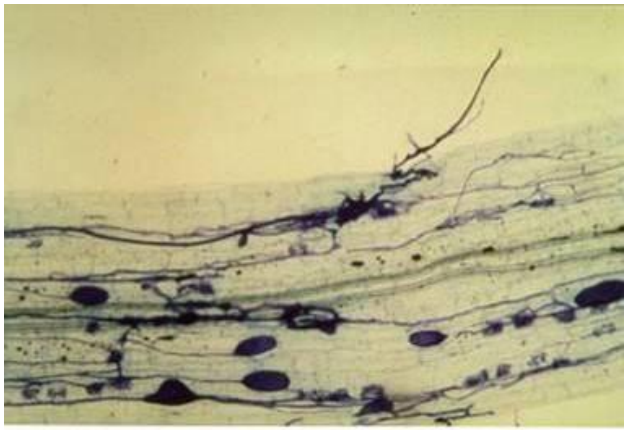
Bio/Organics™
Mycorrhizae Inoculants

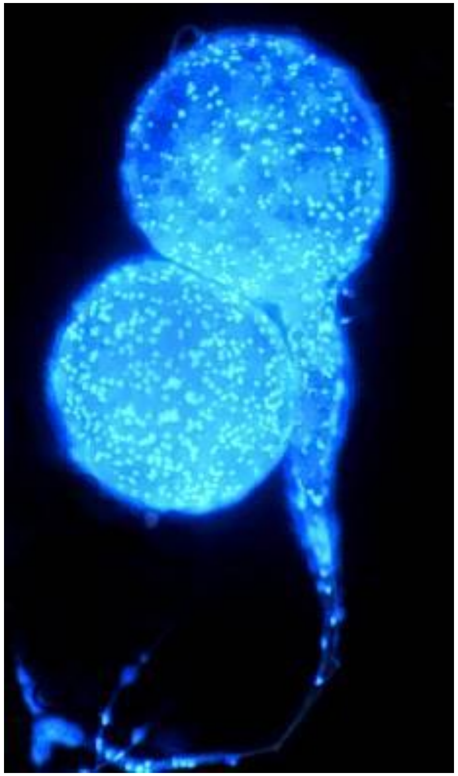
Ectomycorhhizal inoculum
applied in nursery, or at time of transplant

planthealthcare.com
A NATURAL SYSTEM APPROACH™

Arbuscular Mycorrhiza =endomyorrhiza

Fungi belong to Glomeromycota Multinucleous organisms

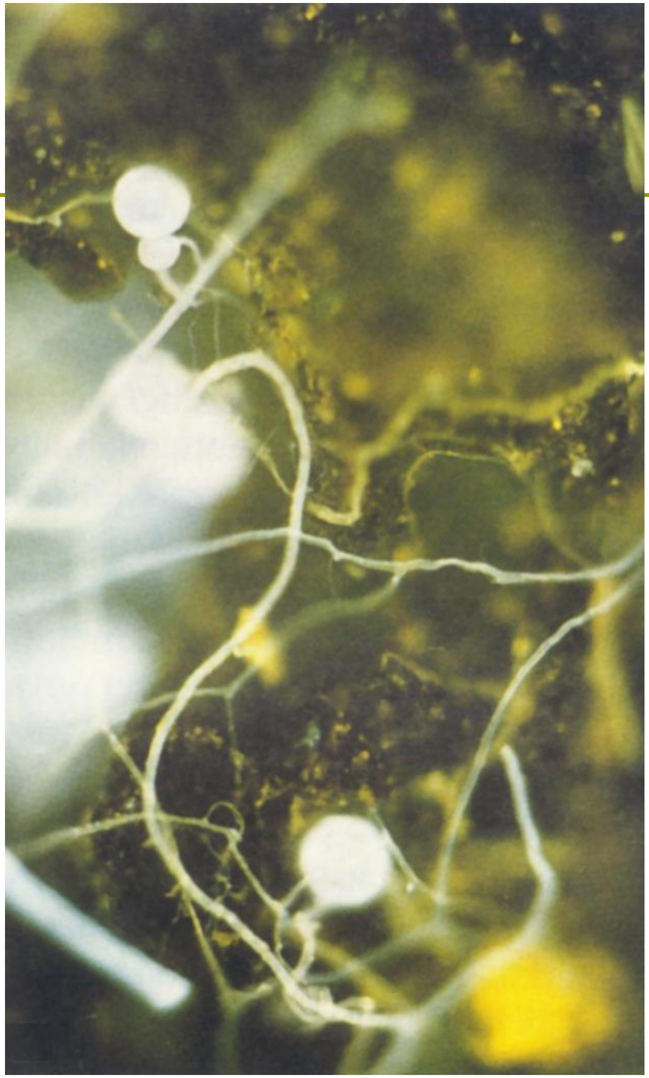


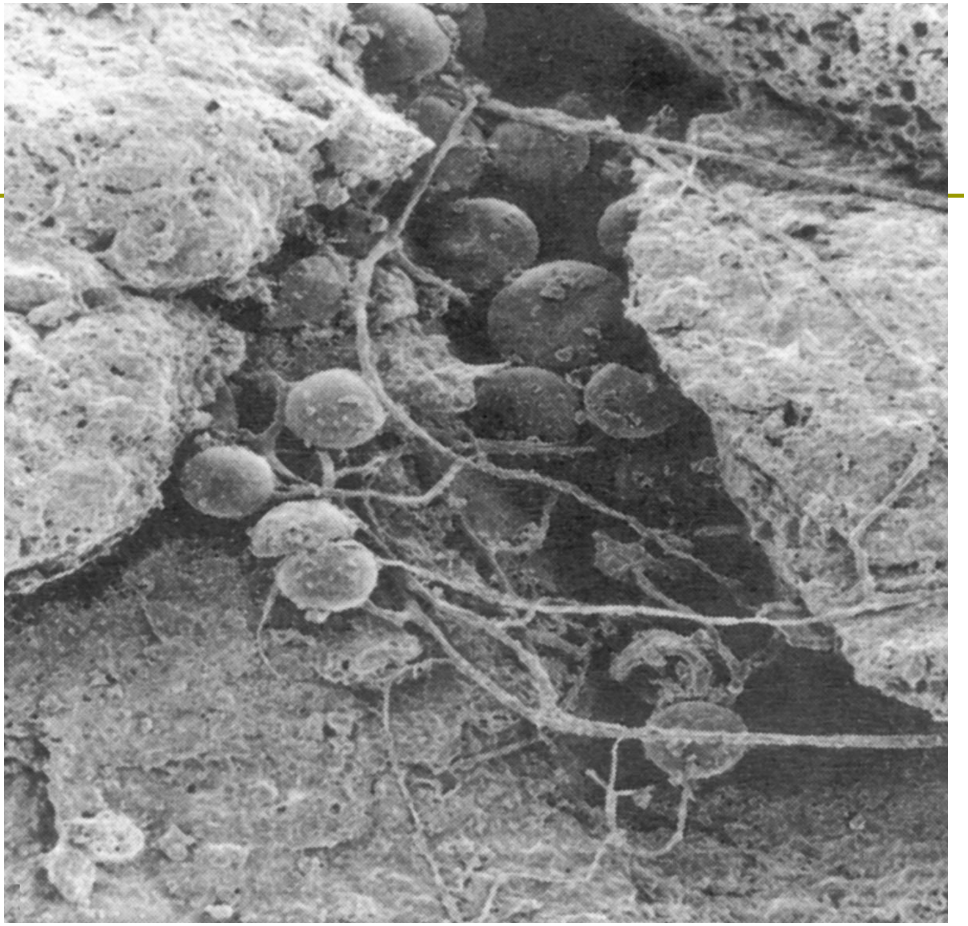


Formed by >70 % of plant species of plant kingdom with about 300 fungal species of the Glomeromycota.

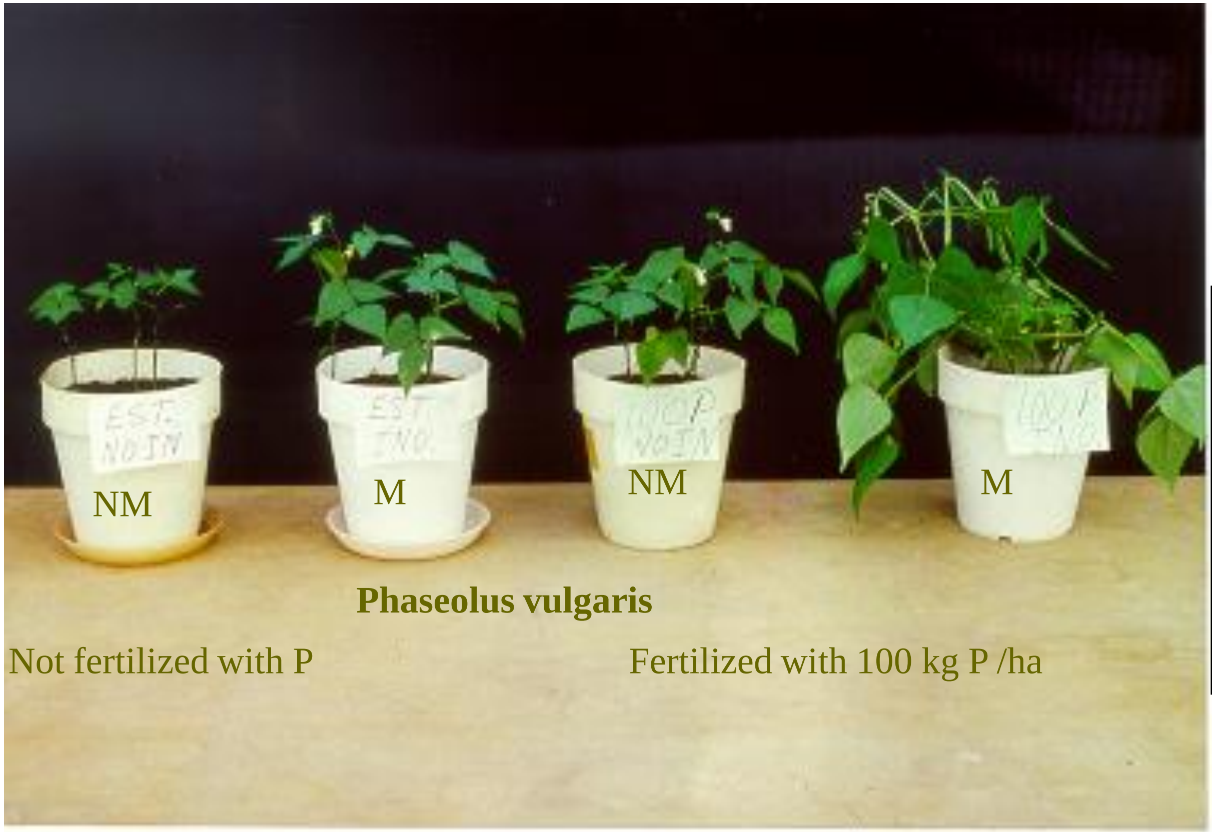
Important crops like all cereals & grasses, potatoes, vegetables, flowers, fruit trees form mycorrhiza.

Some crops never form mycorrhiza: rape, sugarbeet, brassicas
Some need special mycorrhiza: blue berries, Ericaceae, orquideae





Root external mycorrhizal mycelium: increase of exploited soil volume - 6-200 times higher than by roots alone



Mycorrhiza absorbs
Plant available phosphate
More efficient than the root

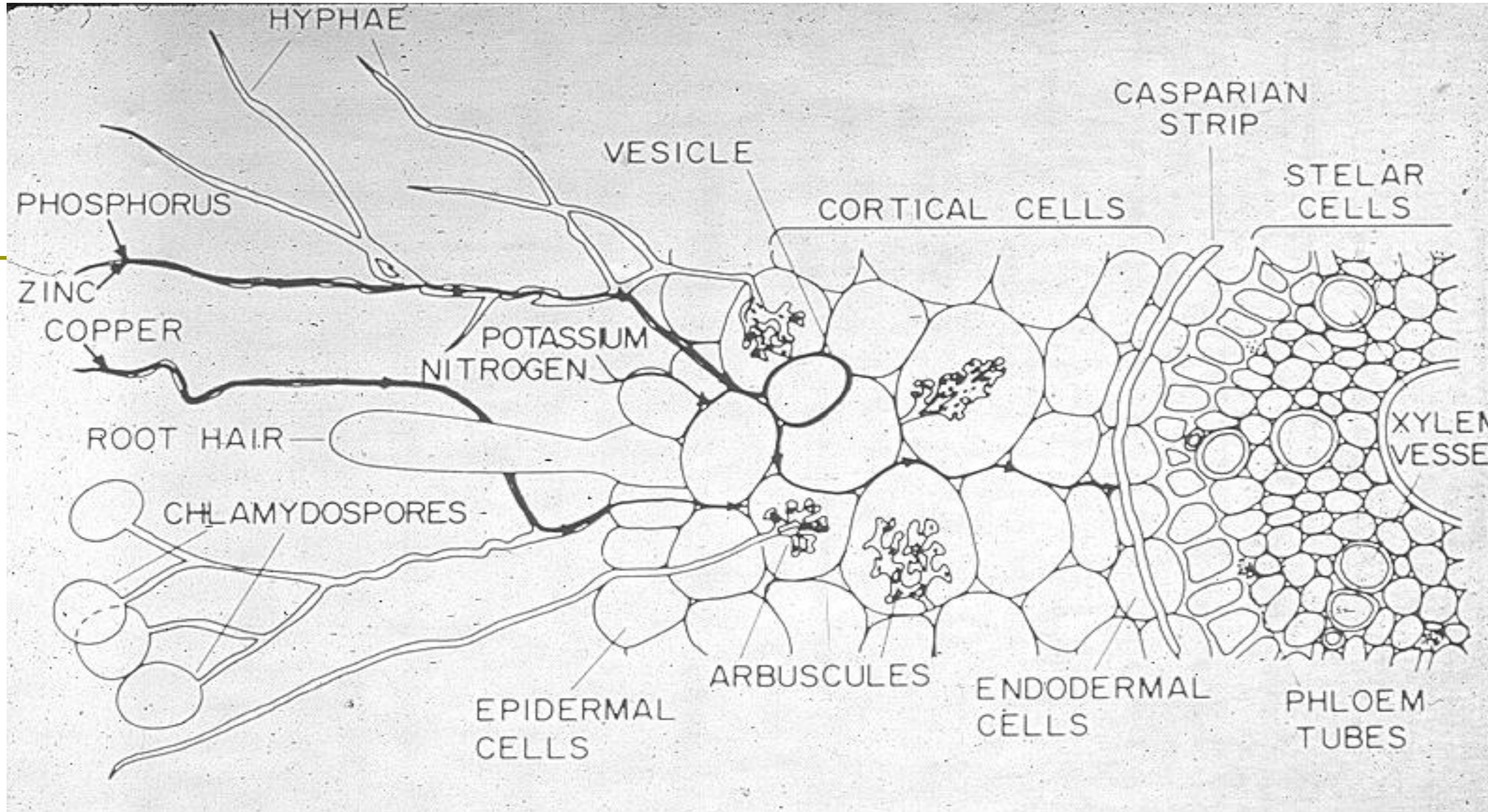
Phosphat is a growth limiting element in soils, and is mainly needed at the beginning of season

Dependency of plants on mycorrhiza:
Some are obligate
Some are facultative

Root Morphology dependent

Onion bulbs grown in soilless mixture (peat/vermiculite/perlite) and treated (A) or not (B) treated with BACTOLiVE AM BASIC inoculum (after 3 weeks of inoculation

Other Nutrients



Macro nutrients: direct uptake and transport by hyphae:

P, NO_3^-, NH_4^+, Ca, Mg, (K? - via mass flow?)

Micro nutrients: direct uptake & transport by hyphae:

Zn, Cu, S, B, Mo (essential nutrient)

Cd, Ni, Sr, Se (heavy metal)

Br, J (not essential elements)

Indirect? (Higher concentrations in mycorrhizal plants):

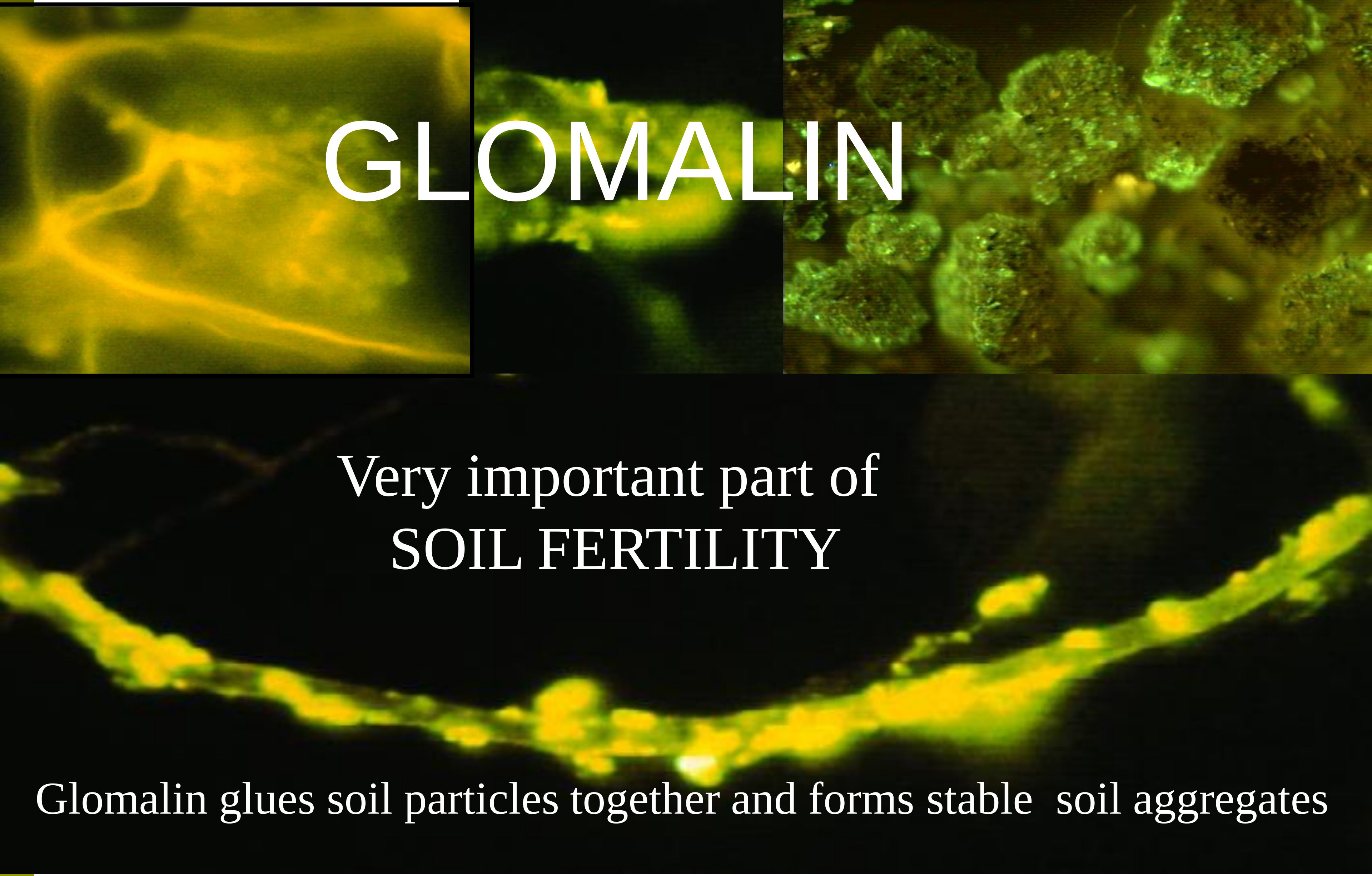
Fe, Mn, Cl (assumed also Na, Co, Si)

Other benefits of Arbuscular Mycorrhiza (AM)

Plant water relations

- Plant health (bio control of root pathogens and
  more resistant to nematodes)
- Interaction with soil microorganisms
  - AM improve biological N2 fixation by Rhizobia
  - AM improve plant growth promoting bacteria and P solubilizers

Nematode control in vegetables by arbuscular mycorrhiza



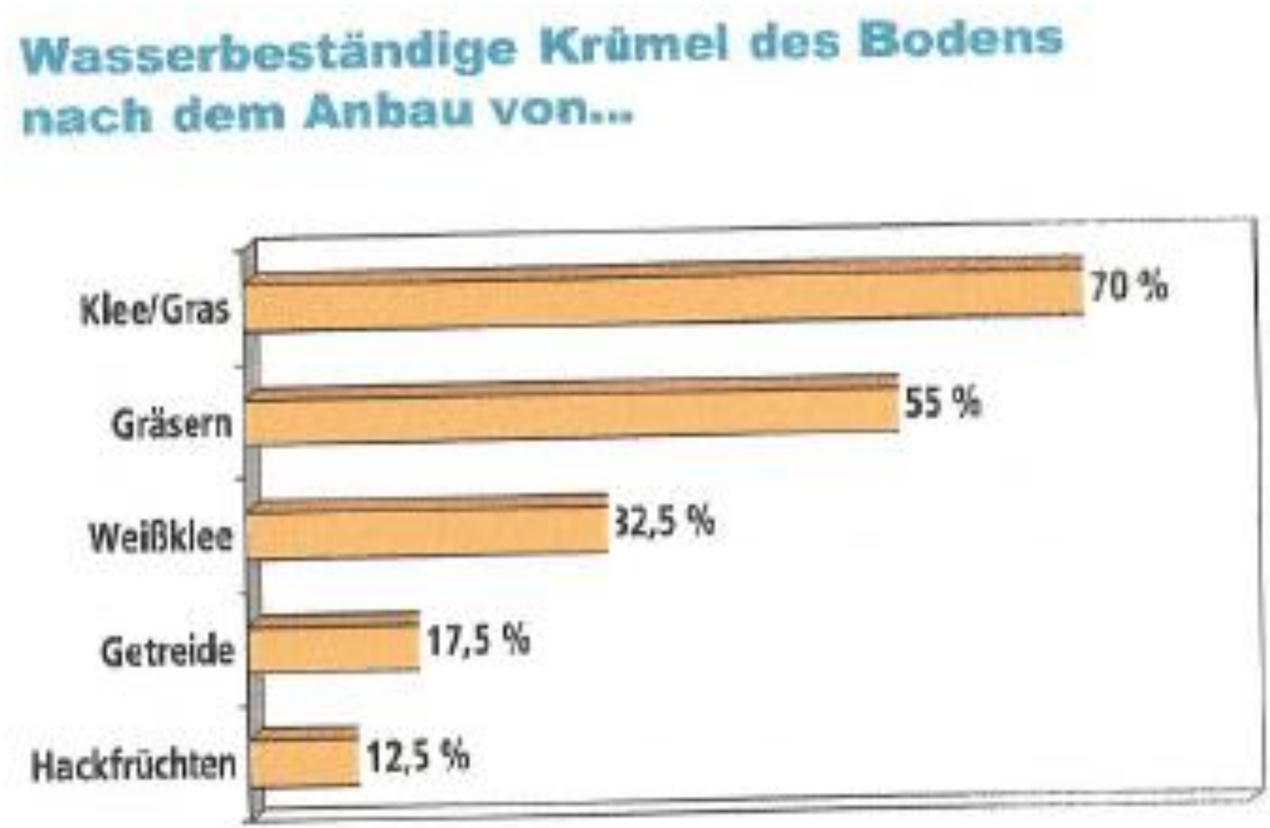
GLOMALIN

Very important part of
SOIL FERTILITY

Glomalin glues soil particles together and forms stable soil aggregates

Potentially the most important benefit of mycorrhizal fungi for a sustainable agricultural production

Water stable aggregates (by Glomalin)



Grasses and legume are heavy mycorrhizal – excellent soil aggregation
Sugar beet doesnot form mycorrhiza – no soil aggregation

Water stable aggregates

Practical value of arbuscular mycorrhiza

- Savings of 50% Phosphate fertilizer, if mycorrhiza is promoted
- Making more effective use of fertilized P
- Making use of low soluble P-fertilizers (rock phosphates)
- More balanced uptake of fertilizer nutrients (N, K, Mg, micro-nutrients)= with better plant growth
- Better survival of plants during short drought periods
- Significant better N-fixation by legumes via Rhizobium
- Plays role in soil health (nematode control) and in soil aggregation (soil fertility)

Summary

- Without roots no shoots = without roots no yield
- Early root development depends (in general) on availability of phosphate; it is well known that too much nitrogen overproportionally favours shoot development
- Optimum root development at the start of the vegetation is important for yield (nutrient use efficacy, water use efficacy)
- It appears that a lot of research is still required what roots concern, and what their symbionts concern – more needs to be done to make optimum use of the natural resource „root“ in agricultural production (it appears that more emphasis is placed on „fertilizing“ the above ground part of crops – root research means: a lot of dirty work)
- Roots are generally living in association with surrounding microorganisms, or in symbiosis with them – without microorganisms there is no plant nutrition & likely low yields.

THANK YOU VERY MUCH